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ABSTRACT

Presented are guidelines for instructors of two courses in the design, installation, and operation of solar heating and cooling systems. These courses are: (1) Design of Systems, and (2) Sizing, Installation, and Operation of Systems. Limited in scope to active solar systems for residential buildings, these courses place primary emphasis upon space and domestic water heating systems. Teaching suggestions, background information, tips on course organization, and some updated handout material are provided in this manual. Both courses utilize classroom lectures together with laboratory exercises. (WB)

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Instructor's Manual for Teaching the Practical Courses on Design of Systems and Sizing, Installation and Operation of Systems for Solar Heating and Cooling of Residential Buildings

Colorado State Univ, Fort Collins

Prepared for

Economic Development Administration, Washington, D.C.

June 1979

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INSTRUCTOR'S MANUAL
FOR
TEACHING THE PRACTICAL COURSES ON
DESIGN OF SYSTEMS
AND
SIZING, INSTALLATION AND OPERATION OF SYSTEMS
FOR
SOLAR HEATING AND COOLING OF RESIDENTIAL BUILDINGS

PREPARED FOR

ECONOMIC DEVELOPMENT ADMINISTRATION
DEPARTMENT OF COMMERCE
WASHINGTON, D. C.

GRANT NO. 99-06-09413-2

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Solar Energy Applications Laboratory
Colorado State University

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The Solar Energy Applications Laboratory at Colorado State University in cooperation with the NAHB Research Foundation, developed two practical training courses complete with training manuals for design, installation and operation of solar heating and cooling systems for residential buildings. One course is titled Design of Systems and the second, Sizing, Installation and Operation of Systems. Both courses were developed with financial support from the Economic Development Administration, U.S. Department of Commerce, Colorado State University (CSU) and the U.S. Department of Housing and Urban Development. This manual is a guide to teachers of the design and installation courses. It provides explanations for the organization of the training courses.

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INSTRUCTOR'S MANUAL

FOR

TEACHING THE PRACTICAL COURSES ON

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AND

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FOR

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PREFACE

The Solar Energy Applications Laboratory at Colorado State University in cooperation with the NAHB Research Foundation, developed two practical training courses complete with training manuals for design, installation and operation of solar heating and cooling systems for residential buildings. One course is titled Design of Systems* and the second, Sizing, Installation and Operation of Systems**. Both courses were developed with financial support from the Economic Development Administration of the U. S. Department of Commerce, Colorado State University (CSU) and the U. S. Department of Housing and Urban Development.

Recognizing the desirability to implement the training courses widely throughout the country, a teacher training course was also developed at CSU to train a cadre of teachers to teach the courses. This manual is a guide to teachers of the design and installation courses. It provides explanations for the organization of the training courses, some background for each module, suggestions in teaching the modules, and additional or updated material when appropriate. Reference is made at the heading of each section in this manual to appropriate modules in the two training manuals.

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*Solar Heating and Cooling of Residential Buildings, Design of Systems, S/N 003-011-00084-4.

**Solar Heating and Cooling of Residential Buildings, Sizing, Installation and Operation of Systems, S/N 003-011-00085-2.

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1 ORIENTATION

(Module 2, Installation Manual; Module 1, Design Manual)

1.1 INTRODUCTION

The courses are oriented to the practical aspects of design and installation of solar systems, and directed to engineers, architects, HVAC contractors and other practitioners in the building industry. Each course is designed for 44 hours of instruction and laboratory practice. During this period of time, every trainee is expected to learn the principles of design and installation of solar space heating systems, solar water heating systems, integrated solar space and water heating systems, and the fundamental principles of solar cooling. They are also expected to achieve a basic understanding of the economics of solar syst The classical approach of classroom lectures and directed laboratory practice is used in the instruction of the courses.

1.2 CONTENT LEVELS

The two courses contain the same subject matter but the content details are different. The differences are often subtle, and instructor of these courses must be aware of the need for emphasizing different details in the two courses as related to the distinct functions of design and installation. The course, Design of Systems, is oriented to engineers, architects and contractors who have primary interest in designing systems, while the course, Sizing, Installation and Operation of Systems is directed primarily to installers of systems. In both courses the principles of system operation are fully discussed.

The "Design" course is oriented to provide detailed methods of determining collector area and sizes of system components for effective system operation. The Installation course provides an approximate collector sizing methodology with a minimum of computational detail. While installers of HVAC systems in large buildings would not normally undertake the task of mechanical designs, in residential applications HVAC installers seldom consult engineers or architects but rather make independent decisions on selecting the heating and cooling system. It is believed that an HVAC contractor, when contacted by a homeowner about a solar system, should be able to choose a system without consulting an engineer. He therefore must have knowledge about properly sizing the system and components and about estimating the probable contribution of solar energy to the total heating demands.

The computations in the Design course are more detailed than in the Installation course. The Design course progresses from approximate "hand" methods to detailed computer-aided techniques, while in the Installation course only an approximate "hand" calculation method is taught. Other modules in the courses are therefore appropriately prepared for the two different levels of detail. Differences are described module by module in this manual and suggestions are made to guide teachers of these courses on the manner of presentations.

1.3 COURSE OBJECTIVES

The objectives of the Design course are to develop capabilities of the trainee to:

1. Design solar heating and cooling systems for residential buildings, make system performance estimates and conduct an economic analysis of the system.

2. Advise clients on the type of system best suited for their needs.

3. Plan and supervise installations of solar systems.

4. Explain basic operating characteristics of solar heating and cooling systems to installers and other concerned individuals.

The objectives of the Installation course are to develop capabilities of the trainee to:

1. Choose a suitable solar heating and/or cooling system for a particular application from among numerous possible system arrangements.

2. Estimate the proper size of the solar system for a particular building.

3. Install a system in the most expeditious manner at minimum cost.

4. Recognize potential maintenance components in a solar system.

5. Explain basic operations of solar systems to potential customers.

1.4 SCOPE

The courses are limited in scope to solar systems that are appropriate for residential buildings and primary emphasis is placed on space and domestic water heating systems. Solar cooling systems are not extensively discussed as they are not as yet (1978) economically competitive with standard air conditioning systems. However, where solar heating systems can be economically justified, adding solar-operated cooling units into an integrated heating and cooling system may soon become economical in some regions of the United States.

The solar systems discussed in the training courses are active solar systems, that is, hardware and moving machinery are involved to collect, store and deliver heat to the load. While passive solar heating methods are of great interest, not enough is yet known (in 1978) to make performance estimates, and definitive design guidelines have not yet been adequately tested. The subject of passive solar heating and/or cooling systems is sufficiently broad so as to justify an entirely separate course.

1.5 ORGANIZATION

The suggested organization of each training course, is provided in the introductory module; Module 1, Design Manual, Module 2, Installation Manual. As seen in the schedules which are reproduced in Figures 1 and 2, each course begins with a half-day tour of solar houses. As time progresses, it may become less important to conduct the pre-course tour, but presently, trainees are not sufficiently acquainted with solar systems so that a preview of various solar houses will prove valuable.

Following the tours, an informal reception is a useful function to acquaint participants with each other and with the instructors. A dinner following the reception is suggested. The reception period is also useful for determining the backgrounds of the participants and their general familiarity with solar systems. A brief self introduction helps people to become better acquainted. This can be done either at the reception or at the dinner. It would be helpful to have a list of participants available during the self-introduction period.

	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
0800		MODULE 1 (30 min) Course Orientation MODULE 2 (90 min) General Description of Solar Heating and Cooling Systems	REVIEW AND QUESTIONS (30 min) MODULE 7 (90 min) Detailed Design Methods	REVIEW AND QUESTIONS (30 min) MODULE 11 (90 min) Collectors	REVIEW AND QUESTIONS (30 min) MODULE 15 (90 min) System Controls	REVIEW AND QUESTIONS (30 min) MODULE 20 (90 min) Design Case Study
1000		COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)
		MODULE 3 (90 min) Solar Radiation Information for Design Purposes	MODULE 7 cont (30 min) Detailed Design Methods MODULE 8 (60 min) Economic Considerations	MODULE 11 cont (30 min) Collectors MODULE 12 (60 min) Storage Systems	MODULE 16 (90 min) Selection of Subsystem Components	MODULE 21 (45 min) Structural, Mechanical and Scheduling Considerations MODULE 22 (45 min) Future Prospects for Solar Heating and Cooling Systems
1200		LUNCH (60 min)	LUNCH (60 min)	LUNCH (60 min)	LUNCH (60 min)	LUNCH (60 min)
1300	1400 - Registration 1445 - Solar House Tours	MODULE 4 (60 min) System Design Guidelines MODULE 5 (60 Min) Heating and Cooling Load Analyses	MODULE 9 (120 min) Energy Conservation Tradeoffs	MODULE 13 (120 min) Laboratory	MODULE 17 (120 min) Solar Cooling Systems	MODULE 23 (60 min) Buyer's Guide Review and Summary (60 min)
1500		COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)
		MODULE 6 (90 min) Simplified Design Calculations	MODULE 10 (90 min) Detailed Design Calculations	MODULE 14 (90 min) Computer Aided F-Chart Calculations	MODULE 18 (45 min) Automated Design Techniques MODULE 19 (45 min) Service Hot Water Systems	Evaluation of the Course by participants
1700		ADJOURN	ADJOURN	ADJOURN	ADJOURN	ADJOURN
1730	Reception and Dinner					Dinner and Awards

Figure 1. Course Outline, Design of Solar Systems

	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
0800		MODULE 2 (45 min) Course Orientation MODULE 3 (75 min) Introduction to Solar H&C Systems	OPEN DISCUSSION (30 min) MODULE 6 (90 min) Thermal Storage Subsystems	OPEN DISCUSSION (60 min) MODULE 10 (60 min) Solar Heating and Cooling Systems	OPEN DISCUSSION (30 min) MODULE 13 (90 min) Heating Load Calculations	OPEN DISCUSSION (30 min) MODULE 17 (90 min) Cost Effectiveness of Energy Conservation
1000		COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)	COFFEE (30 min)
		MODULE 4 (90 min) Solar Radiation	MODULE 7 (90 min) Service Hot Water Systems	MODULE 11 (45 min) Control Subsystems MODULE 12 (45 min) Operations Laboratory	MODULE 14 (60 min) Solar System Sizing MODULE 15 (30 min) System Economics	MODULE 18 (45 min) Retrofit Considerations MODULE 19 (45 min) Scheduling of Solar Installations
1200		LUNCH (60 min)	LUNCH (60 min)	LUNCH (60 min)	LUNCH (60 min)	LUNCH (60 min)
1300		MODULE 4 cont (60 min) Solar Radiation	MODULE 8 (120 min) Solar Heating Systems	MODULE 12 cont (240 min) Operations Laboratory	MODULE 15 cont (30 min) System Economics	MODULE 20 (60 min) Constraints and Incentives
1400	REGISTRATION Solar House Tours	MODULE 5 (60 min) Fluid-Heating Solar Collectors			MODULE 16 (90 min) Solar System Sizing Calculations	MODULE 21 (60 min) Buyer's Guide
1500		COFFEE (30 min)	COFFEE (30 min)		COFFEE (30 min)	COFFEE (30 min)
		MODULE 5 cont (90 min) Fluid-Heating Solar Collectors	MODULE 8 cont (30 min) Solar Heating Systems MODULE 9 (60 min) Solar Space Cooling Systems		MODULE 16 cont (90 min) Solar System Sizing Calculations	Final Discussion and Critique (90 min)
1700		ADJOURN	ADJOURN	ADJOURN	ADJOURN	ADJOURN
1730	RECEPTION AND DINNER MODULE 1 (30 min) Energy Problem					AWARDS DINNER MODULE 22 Future Prospects for Solar H&C Systems

Figure 2. Course Outline, Sizing, Installation and Operation of Solar Systems

Participants in the Installation course are given a presentation on the energy problem after dinner to set the stage for alternative energy concerns and for solar energy in particular. A realistic appraisal of the energy problem should be presented along with realistic projections of solar energy to supply a portion of the total energy demand. The demand and supply of energy will change with time but it is important to emphasize the exponential nature of energy demand. Unless supply of energy can also keep pace with demand there will be an energy problem. The dinner talk for the Design course is not specified, and there are many options for topics, including a discussion of the energy problem.

The Installation course is organized with discussions of systems and components before engaging in computations for sizing and economics later in the course. With installers, we believe that making complex computations will be discouraging, so a thorough familiarization with solar systems and establishing the need for the computations is desirable before calculations are introduced. The Design course, on the other hand, is organized so that participants will engage in computations from the first day. Because designers are generally more at ease in making computations than installers we believe that introducing design modules at the beginning of the course enhances participant interest. Computations progress from simple approximate methods to more complex techniques and finally to computer-aided methods. The discussions on components which follow generally stress quantitative and interactive features and factors that need to be considered in design calculations. In the Installation course discussions of components are at the beginning and sizing and installation issues are at the end of the course, while in the Design course, sizing and economic considerations come first and discussion of components are at the end of the course. There are advantages and disadvantages to both arrangements, and there is a reasonable amount of flexibility in organizing the course. Both courses are arranged in modules and the modules do not necessarily have to be followed in numerical order, although frequent references to previous modules are made within the present order of the training manuals.

It will be noted that each module in both training manuals have stated objectives for the participants. It is important that teachers emphasize these objectives and take particular note during the lectures to be sure that the objectives are being met. While there is a variety of teaching techniques that can be used, summarizing at the end of each module and reemphasizing the objectives and the most important points in the presentation will make a lasting impact. Summarizing by asking questions of the class can sometimes be an effective way to emphasize important issues. Optionally, a short quiz may be given to determine if the participants are achieving that which is expected of them. Quizes must be used carefully, because participants may react negatively to the entire course because of the examinations. On the other hand quizes are useful to determine if teachers are transferring the knowledge for participants to be able to design and install solar systems.

It is strongly suggested that participant evaluations be made daily on each module with respect to (1) content (2) organization and (3) presentation. Teachers should be responsive to these evaluations and adjust their lectures to suit the particular group of participants. The objectives of the course, after all, are to develop participant knowledge and capabilities. An evaluation of the entire course at the end will also be useful for organizing and presenting the next course.

2 ENERGY PROBLEM

(Module 1, Installation Manual)

This module on the energy problem should be presented so that the role of solar energy with respect to the total energy source can be kept in proper perspective. The instructor should emphasize the concept of exponential growth and how it pertains to energy demand, the magnitude of the national energy problem, the availability of energy resources, and the potential for solutions to the energy problems.

The module is titled "Energy Problem" rather than "Energy Crisis" to distinguish a long-term problem from a critical situation which the word crisis implies. In common usage crisis suggests a critical situation of short duration, with expectations of a solution in the near future. We believe the energy problem is a long-term situation which will continue to apply economic pressures on individuals and nations. Although the problem is over-simplified, the difference between demand and supply of energy can be readily grasped by the participants when the exponential increase in the quantity of energy needed in the next few decades is compared to reasonably optimistic sustained increase in the quantity of energy that can be supplied from national and world resources over the same period. Obviously we cannot use more energy than is supplied, thus a problem arises because the energy supplied will control the economic welfare of the United States (as well as other nations of the world) beyond the next decade.

The consequence of exponential growth is presented graphically using examples that are readily understood. Exponential growth is first explained in terms of financial savings, a subject which should be familiar to everyone. Once the trainee understands the exponential effects of compound interest, other processes which exhibit the same characteristics are explained. World population growth is used as an example because it relates directly to the exponentially growing demand for energy.

A characteristic of exponential growth, which should illustrate its effects, is doubling time. For any commodity whose rate of use is increasing by 7 percent per year the doubling time is about 10 years. Thus if energy consumption increases 7 percent annually, and consumption in 1960 is used as a base, twice that amount was consumed in 1970. In 1980, four times as much energy will be consumed as in 1960, and in the year 2000, sixteen times the 1960 usage may result if the rate of increase remains constant at seven percent.

While energy conservation is necessary and should be practiced, by itself, conservation only delays the inevitable pressure on energy supply unless the increasing rate of energy usage is significantly reduced. For example, in 1973 when the public became aware of the energy problem, conservation practices were put into effect and the rate of increase in energy consumption decreased dramatically. The effect of conservation practices persisted through 1975. Since 1975 however, the rate of increase in energy consumption has resumed pre-1973 rates. In effect, we shifted the energy demand curve 2 to 3 years and gained valuable time for the development of alternative energy sources. It should be noted that even with the discovery of new energy reserves equal to the presently known reserves, we gain perhaps an additional ten years supply of present conventional energy sources because of the effects of exponential growth.

It is noteworthy that the U.S. coal reserves, which should be sufficient to provide our energy needs for 300-500 years, at present rates of usage, will only last 40-60 years if the annual rate of increase is 6½ percent per year. Six and one-half percent per year is the historical rate of increasing coal usage, and is substantially below the projected rate of 10 to 11 percent.

The supply of present energy sources, such as oil and coal will decay exponentially, rather than abruptly because we will gradually reduce the use of conventional energy resources as the cost rises with decreasing supply. This is shown in Figure 1-4. An important aspect which should be emphasized is the effect of steadily and rapidly rising fuel costs, in comparison to the rising costs for capital investment for solar energy systems.

Finally some thought should be expressed as to potential solutions to the energy problem. Two important factors are reduction in per capita consumption of energy and development of alternative sources.

We believe that the energy problem should be stressed to the trainees. Although many of the trainees already may be convinced of the need for developing solar and alternative energy sources, it is important that the trainees understand the energy problem thoroughly so that they can in turn, discuss the problem with others.

3 INTRODUCTION TO SOLAR HEATING AND COOLING SYSTEMS

(Module 3, Installation Manual; Module 2, Design Manual)

In both the Design and Installation courses, the purpose of the introductory module is to provide the trainee with general information on solar heating components and their integration into operational systems for heating buildings. Also included is information on solar hot water systems. The manner in which these systems operate should be stressed but details on all components and systems should be deferred to later modules.

Although some trainees will have some knowledge of solar heating components and systems, others may have no knowledge about them. To a certain extent, therefore, these modules are intended to bring the latter group up to a level comparable with the former. At the conclusion of these modules, all trainees should have a general understanding of the principal types of solar heating systems and how they operate. Because there will likely be a mixed audience of initiates and those with some knowledge of solar systems, many detailed questions will be raised. It would be wise to defer responses to the detailed questions until after the modules on components have been discussed.

In the "Installation" manual, there is brief mention of passive solar heating with an explanation that omission in the course is deliberate. The instructor may wish to include an introduction to passive heating methods, but there will be insufficient time in the course to devote more than one or two hours to the subject. It should be pointed out that passive solar heating designs is a subject of intensive research and development at the present time (1978) and as yet, there is inadequate information on design and performance estimating procedures.

The "Design" manual contains descriptions and pictures of several solar heated private homes and three experimental solar heated buildings at Colorado State University. These are included for orientation purposes, and it should be recognized that some are early prototypes which may not be fully representative of systems being installed today. Most of the solar heating systems in the illustrations are site-built, semi-experimental systems. The indicated costs should not be interpreted as typical of current total installed system prices. If the instructor has information on recently built solar heating systems in his locality, up-to-date data should be used.

In the "Installer's manual, there is brief mention of focusing collectors, even though they are not considered practical for space heating and water-heating applications in residential buildings. Advantages and disadvantages of focusing collectors compared to flat-plate collectors should be discussed.

This module contains substantive information on solar systems and the manner of presentation will have considerable effect on the attitude of the trainees throughout the balance of the courses. Presentations should be made to stimulate their interest, and create a desire for learning the details of solar heating technology. If these modules are not presented in interesting and stimulating fashion, or without adequate explanations, trainees may become bored and may have a bad first impression of the course -- an impression which may be hard to counteract in later sessions. If the explanations are not clear and the questions are not well answered, some trainees may become discouraged and feel they cannot understand subsequent material. It is therefore particularly important that the instructor present these modules with clarity and skill.

4 HEATING AND COOLING LOAD CALCULATIONS

(Module 17, Installation Manual; Module 5, Design Manual)

Calculating the expected heating and cooling loads in buildings is an important part of determining an economical solar collector area to be used in a solar system. For non-solar heated buildings, heating load calculations are seldom made; but for a solar-heated building, reasonably detailed calculation of loads is necessary for economically sizing the collectors and components of solar systems. When the cost of energy (gas, oil or electricity) was low, the inefficiency of a furnace due to oversizing was not particularly important. Therefore it was considered unimportant to make careful heating load calculations to size a furnace. Oversizing a solar system, however, can result in a very expensive mistake. Reasonably careful load calculations are recommended when designing solar systems for the building.

There are many methods and procedures used in the HVAC industry for calculating building heating and cooling loads. The procedures used in both the Design and Installation courses are simplified from the ASHRAE Handbook of Fundamentals (1972). The participants should be told that more detailed computational procedures are described in the references listed at the end of Module 5 in the Design manual, and Module 13 in the Installation manual.

The level of effort devoted to heating and cooling load calculations in each course is commensurate with the computational level built into the two courses. The computational procedure in the Design course is more detailed than in the Installation course. Heat transmission losses are estimated by determining the U factors for wall components and infiltration losses are determined by the air change method. Internal heat gains are neglected in the calculations, because they are, to a certain extent, included in the degree-day determination. Long-term building heating loads are computed on the basis of average degree-days for various regions of the country.

In some computer-aided solar system design procedures, the overall UA of the building is needed and long-term monthly and annual heat losses are calculated within to the computer program from stored degree-day information. In most hand computation methods the monthly and annual heat loads are estimated by using the degree-day data provided in the modules. There is no need to provide supplementary information for either Module 5 (Design) or Module 13 (Installation) for the trainees to learn how to calculate heating loads.

The cooling load calculation is not included in the Installation course. At present, solar cooling systems are more a matter of interest than a practical, economic reality, and there are no detailed sizing procedures for solar cooling systems in the course. In the Design course a simplified procedure for estimating cooling load is described because with knowledge of system details given in the course, a designer could estimate the performance of a solar cooling system. The procedure used to calculate cooling loads is essentially a simplified Design Equivalent Temperature Difference (DETD) method which is described in more detail in the ASHRAE Handbook of Fundamentals.

The participants in the Installers course are provided with a problem at the end of the module. They should make the calculations with the help of instructors, using the worksheets provided. Individual work may be designated or working in teams of two may be encouraged, but attention to individual problems should be given by the instructors.

A problem is not assigned in the Design course. Rather, a detailed solution to a problem is worked out in the manual, and a part of the alotted time should be devoted to discussing the essential features of the calculations, such as heat losses from insulated walls and ceiling compared to heat losses through windows, and comparison of heat transmission losses to infiltration loads. By following the example in detail, the teacher may emphasize important aspects of building design on the magnitudes of heating and cooling loads, and the relative importance of insulation, say, to reducing window areas and decreasing infiltration of cold air into buildings.

This module on heat load calculations should precede the discussion of energy conservation trade offs, Module 9 in the Design Course and Module 17 in the Installation Course. The significance is that a reasonably thorough understanding of the relative quantities of heat losses through walls, ceilings, windows, doors and by infiltration will lead to better understanding of the economical trade offs of various energy conservation features in buildings.

5 SOLAR RADIATION

(Module 4, Installation Manual; Module 3, Design Manual)

The purpose of this module is to provide the level of information necessary for trainees to design solar systems. The explanations are not meant to be academic treatises of the subject of solar radiation. The module begins with general background information concerning the nature of solar radiation and instructors may add supplementary material as desired. It might be helpful to some trainees to understand that the solar energy which is converted to heat by the collectors is not only the visible band, but a substantial portion of the near infrared band. The useful spectrum of solar energy for space heating and cooling systems is shown in the figure below.

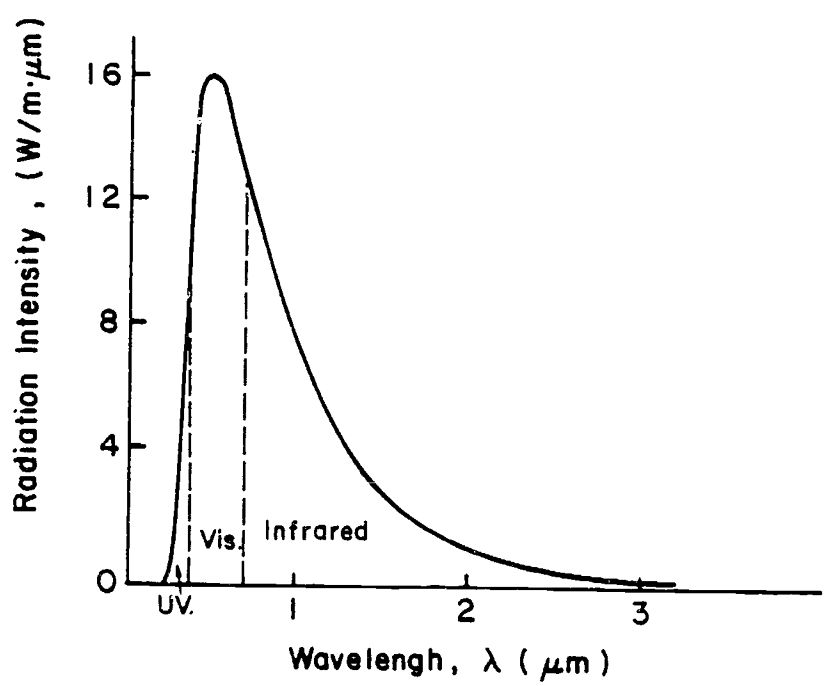

Figure 3. Useful Spectrum of Solar Energy for Space Heating and Cooling Systems

5.1 DESIGN MANUAL

The design techniques in the course are based upon long-term averages for solar radiation. Because there have been a limited number of measuring stations in the United States, this information is available only at selected locations and then only for hemispherical radiation on a horizontal surface. To determine the radiation on a tilted surface, it is necessary to convert this information from a horizontal surface to a specific tilt angle of the collector array. The material in the Design manual includes a discussion of how to first obtain the average daily radiation on a horizontal surface from tables or charts and determine the fraction of extraterrestrial radiation which reaches the surface of the earth at any location. It is important in presenting this material to the trainees to stress that they need not be concerned with solving equations. All design values can be determined from charts, graphs or tables. It could be helpful on the other hand to point out the meaning of the equations for those who are mathematically inclined.

The final step in the process of determining the radiation incident on a collector needed for design purposes is to convert the average daily radiation from a horizontal surface to a tilted collector surface. It is important that the example problems be thoroughly understood as they illustrate the use of each set of tables and graphs (figures) presented in the module.

5.2 INSTALLATION MANUAL

It is definitely not appropriate in the Installation course to discuss analytical relationships such as those presented in the Design course for determining the radiation on a tilted surface. Excessive amounts of mathematical detail will only confuse and discourage the trainees in this course. On the other hand, the trainees should understand the variable nature of solar energy, annually, monthly, daily and even hourly. The only solar information presented is radiation on a horizontal surface. The sizing method presented is approximate and is based only on the January insolation on a horizontal surface. An important point to be made is that more accurate techniques for sizing collector areas necessarily involve the use of more detailed information, and is not appropriate for this course. The detailed methods are included in the Design Manual.

6 FLUID HEATING SOLAR COLLECTORS

(Module 5, Installation Manual; Module 11, Design Manual)

The purpose of the collector module in both courses is the same -- to acquaint the trainee with the technology pertaining to the most important component of a solar heating system, the collector itself. In the Installation course, emphasis is placed on the description of the collectors, the materials of construction, and the methods and characteristics of operation. The Design course contains, in addition to those topics, the fundamental principles of collector design, including a detailed quantitative explanation of the factors affecting solar collection efficiency.

The exceptional importance of the collector in solar heating systems makes it essential that the instructor be very well acquainted with the technology. In addition to thorough familiarity with the materials in the training manuals, the instructor should obtain technical data sheets from the leading manufacturers of solar collectors. Some materials of this type may be included in the module entitled "Buyer's Guide", later in the course. It is recommended, however, that the instructor be well prepared to answer questions arising in the teaching of the collector module. Answers may be aided by familiarity with manufacturers' literature. Chapters 6, 8 and 10 in the ASHRAE book, "GRP #170, Applications of Solar Energy for Heating and Cooling of Buildings," are excellent reference material for the instructor.

6.1 INSTALLATION MANUAL

The first part of the module is primarily descriptive, relating to the principal types of flat-plate collectors and their components.

Following brief presentation of the principles, the main types of liquid-heating collectors and air-heati ...llectors are described. Emphasis is placed on the types of collectors and the components thereof, being commercially manufactured in large quantity. Glass covers, copper absorber plates (for liquids) antifreeze solutions for liquid collection are emphasized in preference to some of the options which are less frequently encountered. Corrosion control, freeze protection, and uniform flow distribution are important considerations in liquid collectors, and are therefore covered in some detail. ...ussion of some air-heating collectors is brief but particularly impor...nt, since their use in residential space heating is growing rapidly.

The primary emphasis on collector efficiency, from the point of view of the equipment installer, is an understanding of the factors which must be considered in the selection of a collector type and, following the choice of type, the selection of a particular make. The factors involved in collector efficiency should be explained, even though possibly some of the trainees not having engineering experience may not fully understand the relationships shown in the graphs and tables. Figure 5-7, Solar Collector Efficiency, for example, should be used to show the considerable difference in collector efficiency among types of collectors and individual makes, and that efficiency varies greatly with operating conditions. It can be explained that the three factors in the horizontal scale, when combined as indicated, are becoming the standard for collector comparison and evaluation. It may be helpful in the explanation of the significance of these lines to separate the discussion of the numerator and the demoninator in the horizontal parameter.

The influence of $T_i - T_a$ can be separately explained by suggesting that S, solar radiation, be considered constant, and the fraction then is proportional to the difference in temperature between the inlet fluid and the atmosphere. It is then clear that the greater that temperature difference is, in other words, the colder the day or the hotter the fluid being circulated to the collector, the lower is the efficiency of heat collection. The reason, of course, is that the heat losses are greater from the collector when that temperature difference is high. Numerical examples may be helpful in showing this trend. Explanation of the effect of solar radiation, S, can be made by suggesting that the numerator, $T_i - T_a$, be considered constant, and that the solar radiation term be progressively increased. As the solar radiation term gets larger, the value of the fraction in the horizontal parameter gets smaller, so movement to the left in the graph occurs. It can then be seen that the efficiencies are going up as the various lines are followed upward and to the left. In other words, the higher the solar radiation, other things being equal, the higher the efficiency of recovering that radiation.

The table describing and specifying the various collectors shown in the graph can also be used in explaining the features which increase or decrease efficiencies. For example, the selective black collector, number one, has greater efficiency than the black painted collector, number five.

It is important that the trainee not think that the efficiency of solar collection is usually comparable to the better levels which can be read from the graph at good solar and moderate temprature conditions, because variability in the weather results in considerably lower avarage efficiencies. Table 5-7 shows typical efficiencies on a month-by-month basis. It should be mentioned that these figures are representative of complete solar systems, the basis for which comes in a later part of the course.

The final short section is on the subject of assembling collector panels into complete arrays. The sizing of the array is the subject of a later module, and here only the general factors involved in assembling the individual panels are indicated.

The instructor may wish to mention that examples of more advanced types of collectors, (including the evacuated-tube type) shown as number seven in the graph and table are described in the last module of the course. In other words, these evacuated tube-types, focusing types, and some of the other new developments in other components are outlined as "Future Prospects". This is a somewhat arbitrary division and some instructors may wish to describe these other types briefly in the collector module. Omitted from discussion are collectors which have not achieved significant practical use or which can be shown to have poor performance under typical operating conditions.

A liquid collector in which water flows downward over the absorber surface in open channels (the so-called trickle collector), glass covered attic spaces through which air is circulated, are examples which cannot be considered cost effective for general use. Because of high cost and the usual need for sun tracking and the loss of diffuse radiation, focusing collectors, of either the lens or mirror types, are not discussed in the collector module, and are mentioned in the "Future Prospects" primarily for academic interest.

The discussion of transparent covers on page 5-5 is based on the assumption that a non-selective black surface is being used in the collector. The instructor should mention that if selective surfaces are used, (with whatever definition he wishes to include at that point), single glazing will usually provide adequate performance even in cold climates.

The instructor would do well to offer advice to the trainees in respect to the major advantages in factory-built solar collectors over site-built or "home-made" hardware. The construction of an efficient solar collector is an exacting task, not at all suited to "do it yourselfers", or even to skilled tradesmen assembling materials such as metal, glass, insulation, and so on, on a building. An efficient, durable, and in the long run, cost effective solar collector is one that is factory built according to exacting specifications, careful choice of materials, and expert fabrication. In addition to the far greater quality control obtained by factory manufacture, lower labor cost is achieved. The cost of skilled labor for building construction, heating system installation, and the like is much greater than in factories. The collector installer, therefore, should be well versed in the selection of good factory-made collectors and in the assembly and installation of the modules into a well-functioning collector array.

Questions will, of course, arise as to the relative efficiency and cost effectiveness of liquid collectors and air collectors. For space heating, efficiencies of the two systems would normally be comparable, sometimes one being higher and sometimes the other. For residential use, however, the air system has a distinct advantage in durability and freedom from maintenance. Air collectors present no problems of corrosion, freezing, or damage to the building resulting from leakage. Although average total cost of the two types of systems do not seem to differ widely, there appears to be an inherent cost advantage in the air type. For commercial buildings where the size of heat conduits and heat storage are important considerations, the smaller space requirements of liquid piping and water tanks may be significant advantages. But it is suggested that the general subject of air and liquid solar collector comparison be deferred until the systems discussions (module 8, 10 and 11) because the selection is really based on considerations pertaining to the entire system, not the collector alone.

6.2 DESIGN MANUAL

In the Design Course, the collector module is presented as number 11, about half-way through the course. Several presentations to classes of trainees have been made in this sequence but it is now recommended that the instructor seriously consider presenting this topic prior to the discussion of Design Methods, Module 7. There is some basis for recommending that the collector module even precede the Design Guidelines, Module 4. Reasons for the change in sequence are based on the apparent need for clear understanding of solar collector characteristics, their design features, and their general requirements prior to detailed consideration of methods for determining total output of suitably sized units. The collector module does not depend on knowledge of sizing methods, but an understanding of solar collector characteristics is very useful in the appreciation of methods for computing performance and selecting sizes of collectors for meeting specific requirements.

After a brief description of typical flat-plate liquid collectors and air collectors, the general principles of solar collector design are built around the basic heat transfer equation, 11-1 on page 11-4. This equation governs the performance of all solar collectors, and contains the terms defining the conditions of operation and the collector design characteristics. Through the next fifteen pages, explanation and discussion of each term in the equation enables the trainee to appreciate and understand the relative importance of all of the design and operating variables in solar heat collection. The final group of variables in the equation, for example, contains a heat loss coefficient, U_L, and two temperatures. In this equation, collector plate temperature and atmospheric temperature are used. The discussion shows how changes in each of those three variables affect the heat loss from the collector, and in turn, the collector heat recovery. Factors which affect the heat loss coefficient, U_L, are discussed in detail, with reference to Figure 11-3, with separate explanation of the convection loss and radiation loss terms.

Also important in this section is the explanation of procedures for improving collector performance by design changes that influence the value of terms in the equation. For example, reduction in heat loss coefficient, U_L, can be accomplished by reducing the convection loss coefficient through use of additional glass surfaces, evacuated spaces, and by a transparent honey-comb between absorber plate and cover glass. Radiation loss can be reduced by use of a surface having low emmissivity (a selective surface). It is recommended that the instructor follow this presentation in a step-by-step procedure as outlined in the manual. Not only does this technique yield a good understanding of how solar collectors operate, but it shows how collectors can be improved and it also provides the rationale for design procedures. The first term on the right hand side of the equation is of equal importance, and the discussion deals with the significance of each variable-solar radiation, transmissivity of the glazings and absorptivity of the black surface.

On page 11-13, equation 11-2 introduces the convenience of employing collector fluid inlet temperature rather than plate temperature in the design equation. It is very important that the trainee understand why this substitution is desirable and how it can be accomplished while retaining accuracy in the correlation. Explanation of the "heat recovery factor" term, F_R, starting on page 11-13, needs to be carefully made. Figure 11-4 on page 11-15 should be helpful in explaining the relationship between fluid temperature and plate temperature in solar collectors heating water and air.

The collector efficiency equation, 11-3, and its explanation on page 11-17, are of major importance because of widespread use by manufacturers in reporting collector performance. The straight line graphs of collector efficiency, defined in equation 11-3, as a function of $\frac{(T_i - T_a)}{H_T}$ should be carefully explained. The characteristics of each collector are shown by the efficiency line (curve), as in Figure 11-5. The point of intersection of the line with the left-hand axis, that is, the efficiency intercept when the temperature difference-solar ratio is zero, is the numerical value of $F_R\tau\alpha$, and is the maximum possible efficiency of the collector, that is, the efficiency when the heat losses are zero. The slope of the line, that is, the vertical change per unit of horizontal change, is numerically equal to F_RU_L, and is porportional to the heat loss rate from the collector. The steeper is the line, the greater is the heat loss rate.

A third characteristic of the collector is represented by the point at which the line intersects the horizontal axis. This point is the temperature difference-solar ratio at which the efficiency of the collector is zero, in other words, the operating condition at which the heat loss rate is exactly equal to the net solar input rate. Under this condition, no useful collection is possible. If the solar radiation value is known or assumed, and an ambient temperature is selected, the location of this point of intersection can be used in the calculation of T_i, which is the maximum obtainable collection temperature under those conditions. For example, collector No. 1 in Figure 11-5 is seen to have zero efficiency when the value of the temperature difference-solar ratio is 1.3. When operating at a solar radiation level of 300 Btu/hr$\cdot$ft^2) at an ambient temperature of 50^oF, use of the 1.3 ratio shows that T_i would be 440^oF. At this condition, 440 minus 50 divided by 300, equals 1.3.

It can be seen from Figure 11-5 and the associated Table 11-1, that the performance of each collector can also be characterized by knowledge of the two terms, $F_R\tau\alpha$ and F_RU_L, because those two values are sufficient for constructing the efficiency line on the reference graph. The foregoing graph and table are based on the performance of several experimental collectors, and are somewhat outdated by the availability of numerous commercially manufactured collectors. It is therefore recommended that the instructor obtain manufacturers' technical data sheets on their solar collectors, and from the reported efficiency lines, or the values of the two parameters described immediately above, construct a graph of half a dozen currently available factory built collectors. Examples would be Chamberlain, Lennox, Revere, Sunworks, Solaron, and General

Electric. The inclusion of at least one evacuated tube collector is useful in showing the much lower slope of the efficiency line due to a considerably lower heat loss coefficient, U_L.

The development of solar collector principles by the foregoing methods permits a clear explanation of the relative performance of liquid and air collectors as shown on pages 11-22 to 11-25. The instructor should carefully distinguish between collector performance and heating system performance because the other components in the solar heating system so strongly affect the inlet temperature to the collector. The instructor should point out that although the efficiency line for most liquid collectors lies above the line for most air collectors, selection must not be based on that consideration alone. As shown in the comparison calculations on page 11-23, an air collector in a solar heating system involving pebble-bed storage generally operates at a temperature difference-solar radiation ratio considerably lower than that prevailing with a liquid collector associated with a liquid heat storage medium in a space heating system. The collection efficiencies of these two systems are therefore likely to be nearly the same at high solar radiation levels, and the air system may be more efficient than the liquid system at low solar radiation levels. Although the liquid collector is usually more efficient than the air collector at the same fluid inlet temperature, the lower inlet temperature in air systems than usually prevailing in liquid systems results in comparable solar heat recovery rates.

7 STORAGE

(Module 6, Installation Manual; Module 12, Design Manual)

The purpose of this module is to present the common types of heat storage units used in solar systems and to provide guidelines for determining storage volumes for air and liquid systems. Only water storage tanks for liquid systems and pebble-beds for air systems are considered in detail.

The important features of storage units and materials are:

1. The heat capacity per unit volume (or unit mass) in the useful operating range.
2. The operating temperature range (i.e. temperatures at which heat will be added to or removed from the storage).
3. The means of adding or removing heat and any temperature difference resulting in the heat exchange process.
4. Temperature stratification in the storage unit.
5. Electric power requirements (pump or blower) for adding to and removing heat from storage.
6. The container, tanks, or other structural elements associated with the storage system.
7. The amount of insulation required to control thermal heat losses from the storage subsystem.
8. The cost per unit volume (or unit weight) of storage material.

Additional information instructors may use to discuss these characteristics are listed in Table 1.

In discussing pebble beds and water storage, several points should be noted. Temperature stratification in the pebble bed significantly enhances system performance because cool air is always delivered to the

Table 1. Storage Alternatives

Characteristic	Pebble-Bed (Sensible Storage)	Water Tank (Sensible Storage)	Calcium Nitrate (Latent Storage)
1	Large (approximately 1600 Btu/ft^3)*	Average (approximately 3700 Btu/ft^3)*	(1/2 to 1/3 that of water) (approximately 9000 Btu/ft^3)*
2	70°F to 150°F (winter heating)	100°F to 160°F (winter heating)	100°F to 150°F (winter heating)
3	Air passing through rock bed ($\Delta T \approx 0$)	Water mixing in tank (ΔT = 0°F) or heat exchanger between collector loop and storage ($\Delta T \approx 15$°F)	Need space in storage unit for liquid or air to pass through rack of containers (ΔT = 0 to 15°) NOTE: Heat capacity reduced accordingly
4	Excellent	Presently expensive	Not practical
5	~1 percent of useful heat	~1 percent of useful heat	~1 percent of useful heat
6	Simple, box (needs air plenums top and bottom)	Water tank (leak proof, corrosion protection)	(1) Corrosion protection (2) Leak proof (3) Solidification prevention
7	R-13	Need R-30/R-40	Depends on configuration
8	Relatively inexpensive (~$1/$ft^3$)	$1/gallon, glass lined steel	Expensive

* Based on assumed temperaure range of Row 2

inlet side of the collectors. Air collectors are designed for once-through heating. In water tanks the temperature is nearly always uniform, hence liquid collectors are designed to add heat to storage by recirculating warm fluid through the collectors.

Flow of air through a pebble bed that is greater than 8 ft deep with 3/4 to 1-in. diameter rocks, results in excessive use of electrical energy to operate the blower. If the pebble bed is less than 4 ft in depth, the flow distribution through the pebble bed may be nonuniform, resulting in uneven heating of the bed and returning warm air to the collector.

In a water storage unit, a critical factor in the operation of the unit is the necessity for adequate insulation. This factor cannot be over-stressed in importance. While heat losses from a tank located inside the building helps to meet the heating load the heat loss rate is uncontrolled and may result in overheating the building space which is wasteful of solar heat. During the summer, storage heat losses would add to the cooling load, whether or not a cooling unit is available in the building. It is not always feasible to shut down the system during the summer because this would not allow solar heating of the DHW. An insulation thickness of R-30 is a recommended minimum.

The thermal storage volume can be based on the collector area. It is important to remember that a large storage volume does not provide additional heating capability. Figure 4 below shows qualitatively the relationship of storage volume to useful heat provided toward the heating load by the solar system for a fixed collector area. As storage volume increases, useful heat derived from the system increases. Beyond a certain range in volume the incremental useful heat provided becomes small and the additional cost for larger storage capacity is not justifiable for the value of additional heat derived from the system.

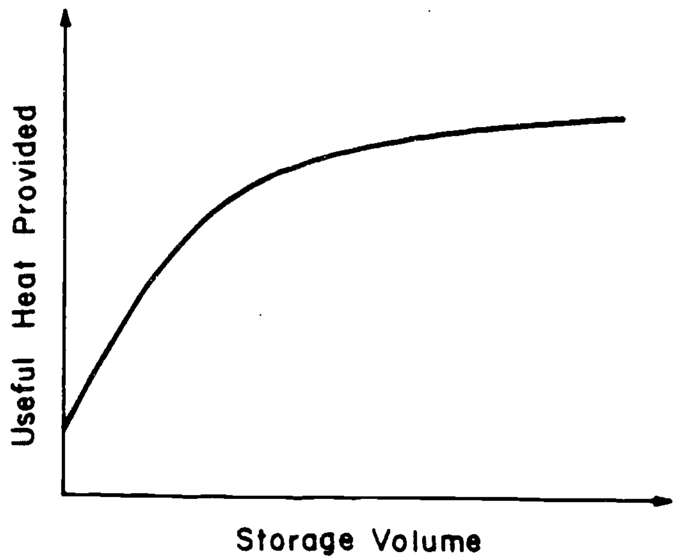

Figure 4. Useful Heat Provided as a Function of Storage Volume for a Fixed Collector Area.

8 SOLAR HEATING SYSTEMS

(Module 8, Installation Manual)

The purpose of this module is to describe solar heating systems in greater detail than was treated in the introductory module (see section 3 of this manual). Liquid-heating and air-heating systems are treated separately and the instructor should emphasize the interactive nature of the components in the system. The efficiency of the collectors is affected by the water temperature entering the collector; which in turn is dependent upon the storage temperature, and the storage temperature is affected by the heating load.

After having discussed the main components of solar systems in separate modules, it is recommended that different operating modes of systems be discussed again in detail. For air systems in particular, the effect of temperature stratification in storage on collection efficiency should be emphasized as this is the main reason why air systems perform as well as liquid systems.

In discussing system operation, it is helpful to the trainees if typical fluid temperatures are mentioned in following a particular fluid circuit, for morning, noon and afternoon conditions. Use of typical temperatures in the discussions helps to conceptualize the flow of heat in the systems.

It is suggested that while following the schematic diagrams of different systems that are included in the module, the location of the auxiliary heating unit in the system be emphasized. In a liquid system, a parallel configuration for the auxiliary water boiler should be recommended because if the boiler is placed in series in the load loop, there is a possibility that auxiliary energy will be stored in the solar storage tank with the consequence that water temperature in storage will remain high at all times. On the other hand, if an air-distribution system is used with the liquid-heating system, and an air-heating furnace is used as an auxiliary, the heat exchanger in the duct should be arranged in "series" with the furnace so that return air from the rooms could be preheated by the solar heated water before passing through the furnace. An air-heating solar system should always have the auxiliary furnace in series so that solar heat will pass through the furnace and if boosting is necessary, auxiliary heat would be added to the solar heated air, thus enabling all the collected solar heat to be utilized.

As system details are discussed, it is recommended that installation and operation issues be specifically addressed. While a separate module in the manual is included for scheduling and most of the installation concerns are covered in the discussions again at that time, it is importnat to emphasize as often as possible the main concerns for system installation. It should be remembered that participants in these courses are assumed to be familiar with standard HVAC practice, so that it is unnecessary to describe how to solder fittings, or make sheet metal ducts. Location of components in buildings, and descriptions of how to install the components are the main issues which will concern installers and perhaps designers who wish to provide installation details in their designs.

The advantages and disadvantages of liquid- and air-heating solar systems can be mentioned while system details are being discussed. The instructor should be careful not to let personal biases enter into the discussions so that trainees are influenced toward one type of system.

It is important that the trainees clearly understand that there are applications where air systems have advantages, and applications where liquid systems have advantages.

The subject of heat pumps as auxiliary heaters is briefly covered in this module. A distinction should be made between solar-assisted (series connected) heat pumps and auxiliary (parallel connected) heat pumps. There is no definitive information at this time (1978) to indicate which arrangement is superior. There are solar installations using both arrangements. It should be emphasized that if a solar-assisted arrangement is used, the temperature of the heat supply to the evaporator should not exceed the manufacturer's specified limit in temperature, otherwise the COP and efficiency of the heat pump reduces significantly.

In a related module in the design manual (Module 16), the selection of pumps, blowers, and heat exchangers, is given considerable attention. These conventional components should be selected carefully so that electrical energy required for system operation does not become excessive. The mathematics required for the calculations of the components may concern a few trainees. The instructor should try to offset this concern by emphasizing the step-by-step procedures detailed in the module. It is desirable to present an example to illustrate that while calculations appear complex, they are in fact relatively simple once the principles are understood.

9 CONTROLS

(Module 11, Installation Manual; Module 15, Design Manual)

The purpose of controls in a solar system is to enable automatic collection and distribution of solar heat, and to integrate the operation of the conventional auxiliary system with the solar system. Controls that are properly installed will minimize the auxiliary energy use, while maintaining the desired comfort conditions in the conditioned space. Trainees are not expected to be able to design and assemble controllers, but they should understand how solar systems are controlled. The module is difficult to present without discussing details, yet presentation of control details is not necessary to either design or install the system. Knowledge of control subsystems is necessary to check the proper operation of a system for system start-up and maintenance purposes.

The modules on control subsystems are different in the two manuals and are consistent with the level of detail desirable in each course. In each manual, there is a brief section with a heading "Control System Check-Out". Discussion of this section should be explained using the material which follows. The material may be duplicated and used as a handout to the trainees.

CONTROL SYSTEM CHECKOUT

It is well to check the control system with a "dry" run through the full sequence of modes. Temperature sensors in the control system are usually thermistors, and a low resistance across the thermister implies a high temperature. Thus if a jumper wire is connected across a particular sensor terminal, the controller "senses" a high temperature for that sensor because the resistance in a jumper wire is low. Similarly, if a low temperature is to be simulated, a high resistance jumper (with a resistor) across the appropriate terminals could be used. To complete a thermostat circuit, the manual adjustment (set temperature) on the thermostat can be moved up or down until the appropriate first, or the first and second stage contacts are completed.

Referring to a representative control unit shown schematically in the following figure, details of achieving out a heat collection mode and a heat delivery mode are described. To collect heat from the collectors, a temperature difference of about 20°F must exist between the sensor at the collector outlet and the sensor at the bottom of storage (or in the duct leading to the collector). If a jumper were placed across TCO to COM (refer to the schematic diagram) a high temperature is indicated and the blower in the air handler (to circulate heat through storage) should turn "on". By observing the position of the dampers it is easy to determine if the air circulation is correct. If the dampers are inside the air handler, check the heat distribution registers to see that no air is circulating into the room. If a multimeter is available, the voltage

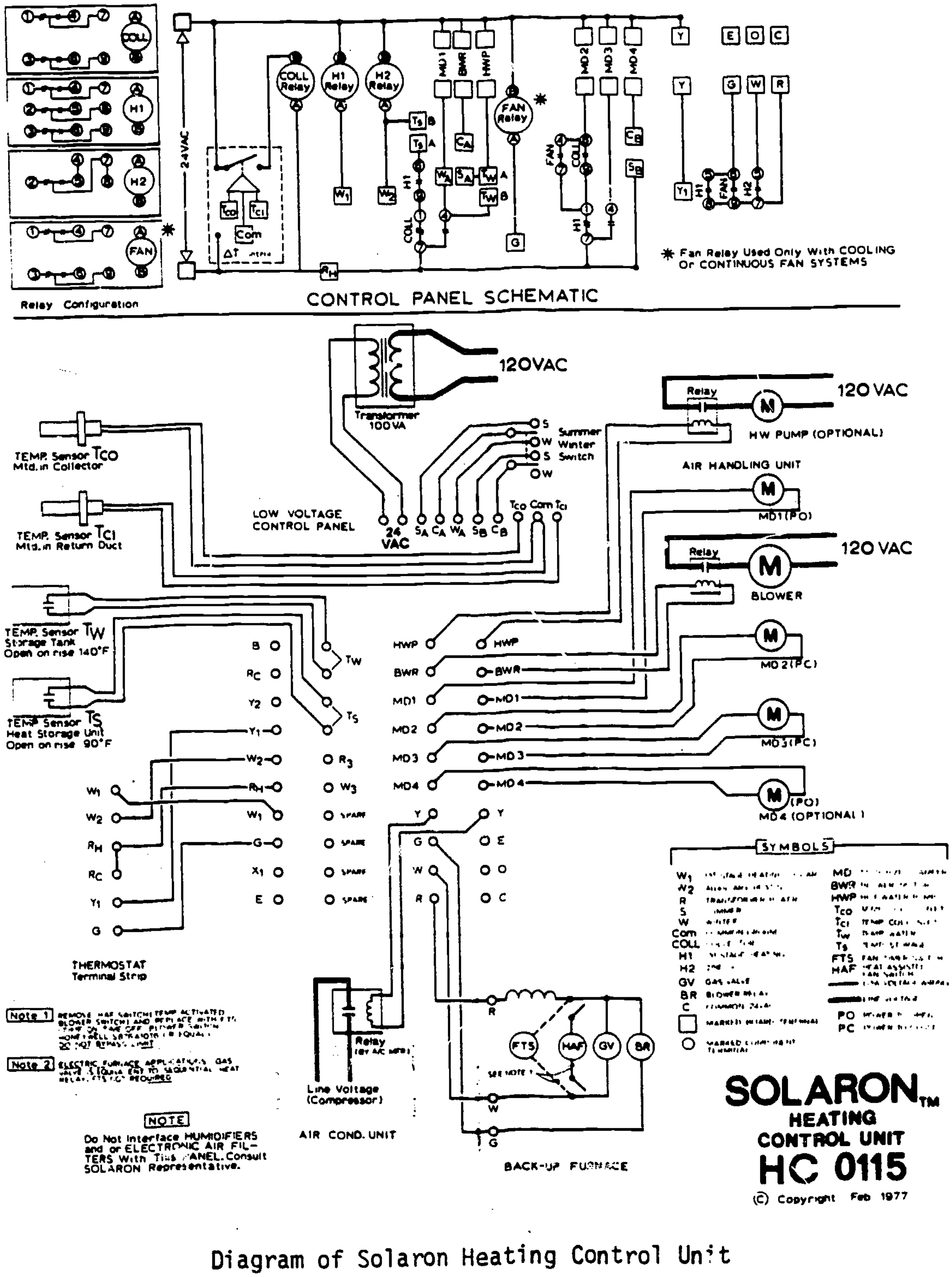

Diagram of Solaron Heating Control Unit

NOT REPRODUCIBLE

across the terminals of appropriate damper motors can be checked to see that they are properly energized, or the resistance across the terminals can be checked to see if the contacts are open or closed as required.

To check if solar heat can be delivered directly to the room from the collector, manually contact the first stage of the thermostat while the jumper is across the TCO-COM contacts. The blower of the furnace should turn on and there should be air delivery through the room registers. Check to see that the auxiliary (gas, oil or electricity) does not turn "on" in the furnace when this check is made.

Finally, turn the thermostat "up" until the second stage contact is made. The auxiliary unit (gas, oil or electric heater) should turn on and there should be hot air being delivered to the rooms.

To check heat delivery from storage, turn the thermostat up until the first stage contact is made. The circulation blower(s) should turn on, and dampers should achieve the required position. If the dampers are inside the air handler, check air flow through the room supply and return ducts. The auxiliary heater (gas or oil burner, or electricity) should not turn on until the second stage contact of the thermostat is made.

There are many possible levels of sophistication in different controllers which require multiple sensor and comparator states to exist simultaneously before a particular mode is achieved. To check out all the modes, it will be necessary to examine each set of conditions in a truth table (which should be supplied with the controller or system) and set the conditions for the appropriate sensors. In most systems there are only a few modes to check, but regardless of whether there are a few or many modes, each should be checked out after the installation is completed.

10 DOMESTIC HOT WATER SYSTEMS

(Module 7, Installation Manual; Module 19, Design Manual)

The rationale for a separate module on domestic water heating systems is that stand-alone water heaters are important applications of solar energy. The sequence of presentation of solar water heater system types are arranged with the simplest system, the thermosiphon type, presented first, along with some general principles. Progressively increasing equipment requirements (and usually with increasing costs), redirecting pumped circulation type, the same with freeze-protection by drainage, and finally the dual fluid-types with heat collection in a non-freezing liquid or in air and transfer to water in a heat exchanger are successively described. This step-wise presentation permits a clear understanding of why each design change is necessary and how it is accomplished.

The diagrams in the manual apply to several general types of solar water heaters, and are not based upon specific manufacturers' designs. It is suggested that technical data sheets be obtained from several solar water heater manufacturers for class distribution which show the detailed piping and control diagrams. The instructor may wish to substitute diagrams on specific systems for the general counterpart shown in the manual. Photographs of the solar water heaters aid the visualization of equipment size and appearance.

The two principle methods for supplying auxiliary heat are important considerations which the instructor should compare, as outlined in the manual. Examples of the one tank system, (auxiliary heat being supplied in the upper part of the one tank), may be shown by use of the manufacturers leaflets and the two tank system with auxiliary being supplied as in conventional hot water systems, may be covered in similar fashion.

Considerable importance is attached to the discussion of methods for protecting the system from overheating. Various types of venting of steam or overheated water, depending upon system type, should be covered, and again manufacturers literature can be used for detailed coverage. Since possible hazzard to people and damage to equipment can result from inadequate consideration of these requirements, this topic should be emphasized. The section of the manual on water heater performance and the sizing of systems is based largely on some excellent work in Australia. The information is, of course, applicable everywhere, but the performance is dependent on the system type and climatic conditions. Manufacturer's data often contains the sizing information, and the technical data sheets can be referred to for such information. The simplified sizing method shown in the manual, involving Figure 7-9, Installation Manual, and used in the several sizing examples, is satisfactory for most requirements, and can be used as a useful illustration of sizing methods. (The separate curve for Seattle should be eliminated for Figure 7-9.) Another method which has been publicized by the International Association of Plumbing and Mechanical Officials is not recommended, however, because it can be in serious error if relatively small or relatively large fractions of the annual hot water requirements are being supplied by solar. A question may be raised as to the usefulness of sizing and performance data applicable to one type of solar water heater, say the thermosiphon type, in the design of quite a different type, such as a pumped circulation, dual fluid type. Experience has shown relatively small differences in total deliveries of solar heated water from even considerably different types of equipment. It is, however, evident that a more efficient solar collector (for example, one with a selective black coating rather than a non-selective absorber surface), will provide more solar heated water than a less efficient collector. The direct water heating type will provide more hot water than the heat exchange type, and so on. Therefore, if the specific solar collector characteristics and system design arrangements are known, performance and sizing factors may be calculated by using the relative areas method, explained in Section 14 of this manual. Such calculations, in many cases, have already been made by the solar water heater manufacturer, and tables of hot water delivery from systems of various sizes in different regions of the United States are presented, (or under given solar and temperature conditions).

The discussion of cost in the manual is outdated, and the instructor will need to supply more nearly current figures. With the additional experience now in hand, it is very doubtful that the total installed cost of a typical solar water heater for an average American family will be less than $2000 (not $1000 as in the manual). Typical prices of hardware for the entire solar water-heating system, with about 60 ft^2 of solar collector, with tank, pumps, controls, and all accessory equipment are in the range of $1000 to $1500. Dealer markups, installation, labor, and miscellaneous costs bring average current total costs to around $2500. The subject matter of the costs section should be modified accordingly.

It is suggested that local quotations on solar water heater "packages" be obtained by the instructor, both for the equipment itself, and for typical total installed prices. These figures can then be used as illustrations for the trainees.

11 SOLAR COOLING

(Module 9, Installation Manual; Module 17, Design Manual)

The basic principles and concepts of solar cooling methods are presented to familiarize trainees with a few potentially practical systems. Because of the present high cost for solar cooling, it is economically difficult to justify systems for residential applications. However, if the collectors, hot storage, and auxiliary equipment are available for heating, in some cases where electricity costs are high, solar cooling may become economically justifiable.

The instructor should be familiar with standard refrigeration equipment as well as solar cooling equipment. He should be able to make performance comparisons between standard air conditioning equipment and solar cooling machines at least in terms of the COP of each. While evaporative and radiative cooling methods do not involve solar energy, they can be incorporated into solar systems and therefore the subjects are included in the modules.

There are no significant differences in emphasis between the two training courses, although the Munter's Environmental Control (MEC) unit is included in the Design manual while it is omitted from the Installation manual. Inclusion of MEC in one manual and not in the other is strictly arbitrary. In the Design manual a brief discussion of the economics of solar cooling is included to provide additional detail to support the contention that solar cooling is not yet considered an economical proposition. The instructor should substitute current costs in this section whenever differences from local prices are known.

12 SOLAR HEATING AND COOLING SYSTEMS

(Module 10, Installation Manual)

The purpose of the module is to describe the additional components and interfaces required to integrate a solar cooling unit into a solar heating system. It must be recognized at the outset that solar cooling economics are not as favorable as for solar heating for most areas of the United States. Solar cooling systems are becoming commercially available but operating experience with these systems is very limited. The only practical solar cooling unit available for residential and light commercial applications (25 tons or less) is a lithium bromide absorption unit.

In discussing combined solar heating and cooling systems, several aspects should be addressed. These include the operating modes and associated control schemes to optimize the performance of the system, the use of cool storage to improve the overall performance of the system, and the need for auxiliary energy to drive the cooling unit. Alternatively a separate electrically driven air conditioner could be considered.

Another important point to reemphasize in solar cooling is to provide adequate insulation of the thermal (hot) storage tank. Because only liquid systems are currently capable of interfacing with absorption cooling machines, the use of a hot water storage tank is required and unless the heat loss from a hot storate tank placed inside the building is controlled, the useful capacity of the cooling machine will be seriously reduced because of the excess heat released from the hot storage tank into the building space.

13 LABORATORY EXERCISES

(Module 12, Installation Manual; Module 13, Design Manual)

The objective of this module is to present the trainees with an opportunity to check out air and liquid solar systems. If solar houses are not accessible for training purposes, small scale models can be used. Every effort should be made to provide opportunity for some "hands-on" experience. Working with operating solar systems would be ideal, however, if full-scale solar systems are not available, models using commercially available collector modules and reduced size storage and other components can be useful. It is preferable if the trainee can obtain some experience assembling the components of a solar system, but it is difficult in a limited time to provide wide-ranging experience. Much can be accomplished if the laboratory exercises are properly structured, and adequate equipment and laboratory assistance are provided.

Inspection and check out of an operating solar system are very effective instructional tools. The procedure for "dry" run check out of a systm was described in the controls module, but thermal checks of solar systems are also important. Sample sets of temperatures in experimental systems are provided to illustrate some of the major difficulties that can be experienced with solar systems. Instructors should explain the sets of temperatures listed on the check lists and have the trainees identify specific problems discerned from the set of recorded temperatures.

14 DESIGN METHODS

(Modules 14 and 16, Installation Manual;
Modules 4, 6, 7, 10, 14 and 18, Design Manual)

The design methods for solar heating systems range from simple and approximate techniques to accurate and very detailed procedures that involve use of large digital computers. A simple procedure is described in the Installation manual which is consistent with the level of effort expected of HVAC system installers to determine collector array size to provide a preselected fraction of the annual heat load for a building. The method described in Module 14 gives approximate results and the graphical relationship used is site dependent, fixed in orientation and tilt, and is appropriate for the general class of double-glazed flat-plate collectors with flat-black absorbers. A new method, almost as simple as the method in the manual is described in this manual and should be substituted for the material in Module 14, or used in addition to the method described.

It is important to recognize that the new method, called Relative Areas method, enables introduction of specific collectors into the design methodology, which is an extremely important addition to the procedure. However, the instructor should be aware that additional information of collector efficiencies and of the parameters $F_R\tau\alpha$ and F_RU_L must be added in teaching the collector module of the Installation manual. On the other hand, the relative areas method does not require specific solar radiation information because the tables provided include weather and solar characteristics for specific sites in the tabulated values.

Several simple design tools are described in Module 4 of the Design manual, and the relative areas method can be added. However, it is important to note that the module on solar collectors (Module 11) must precede Module 4 as was earlier suggested in Section 6.

The main emphasis in teaching the Design course should be on the f-chart method, described in Module 7. The method is amenable to programmable hand calculators and programs can be written from the equations in the manual. Every trainee should complete an f-chart calculation by "hand" as part of the training. An example is provided in the manual and exercise problems are given in Module 10 with suggested work sheets to organize the calculations. When the hand procedure is thoroughly understood, a computer-aided f-chart design session is suggested as part of a laboratory exercise or evening program. The interactive f-chart computer program is versatile and easy to use, and in fact, the user need not understand the procedure to use the computer program. The instructor should, therefore in most instances, be sure that the trainees understand the f-chart procedure before use of the computer-aided interactive program.

The most detailed procedures are the automated computer programs. In Module 18, the various programs are referenced but no details are given and it is entirely optional for instructors to include this module in the course. If it is desired to pursue the subject, instructors must obtain detailed documentation of TRNSYS (University of Wisconsin) and SOLCOST (Department of Energy) for further study. Documentation for SIMSHAC (Colorado State University) in the form of a Users Manual is not available and therefore is not recommended for use in this course.

The description of the Relative Areas method which follows can be duplicated and provided as hand-out material. Depending upon the background of the class the basis for the me[illegible]y may be explained.

For installers only, it should be sufficient just to describe the procedure. Natural logarithms which are needed in the calculations are usually determinable by hand calculators, and it should be unnecessary to explain what logarithms are.

THE RELATIVE AREAS METHOD

The solar fraction of the annual heating load is the quantity of solar heat provided from the solar system divided by the total annual heat required for the building. The solar fraction, or annual heat delivered by a solar system, is used to compare different systems and to make economic analyses of systems. A simple method for determining F from selected collector areas, January solar radiation and January building load is given in Figures 4-5 through 4-10 of Module 4 in the Design manual. The curves are dependent upon the types of collectors and location. The relative areas method allows different collectors to be used and provides tabulated values for different locations in the U.S. and Canada.

If the solar fraction F for several different collector areas, of a particular type, for a specific building and location are calculated, the results may be as tabulated in the second column in Table 1. If the areas in column 1 are divided by the area which provides 50 percent of the annual heating needs, A_{50}, and the natural logarithm of A/A_{50}, is plotted against F, a straight line could be fitted through the points, as indicated by the solid line in Figure 1. If another collector is used in the calculations, a different line would result, as shown by the dashed lines on the figure. The lines on Figure 1 can easily be identified if the intercept and slope are defined. The other parameter needed to identify the straight line in Figure 1 is A_{50}.

Table 1. F Values for Different Collector Areas

$A(ft^2)$	F	A/A_{50}	$Log_e(A/A_{50})$
500	0.68	1.61	0.48
400	0.59	1.29	0.25
310*	0.50	1.00	0.00
300	0.49	0.97	-0.03
200	0.33	0.65	-0.44
150	0.22	0.48	-0.78

$*A_{50} = 310\ ft^2$

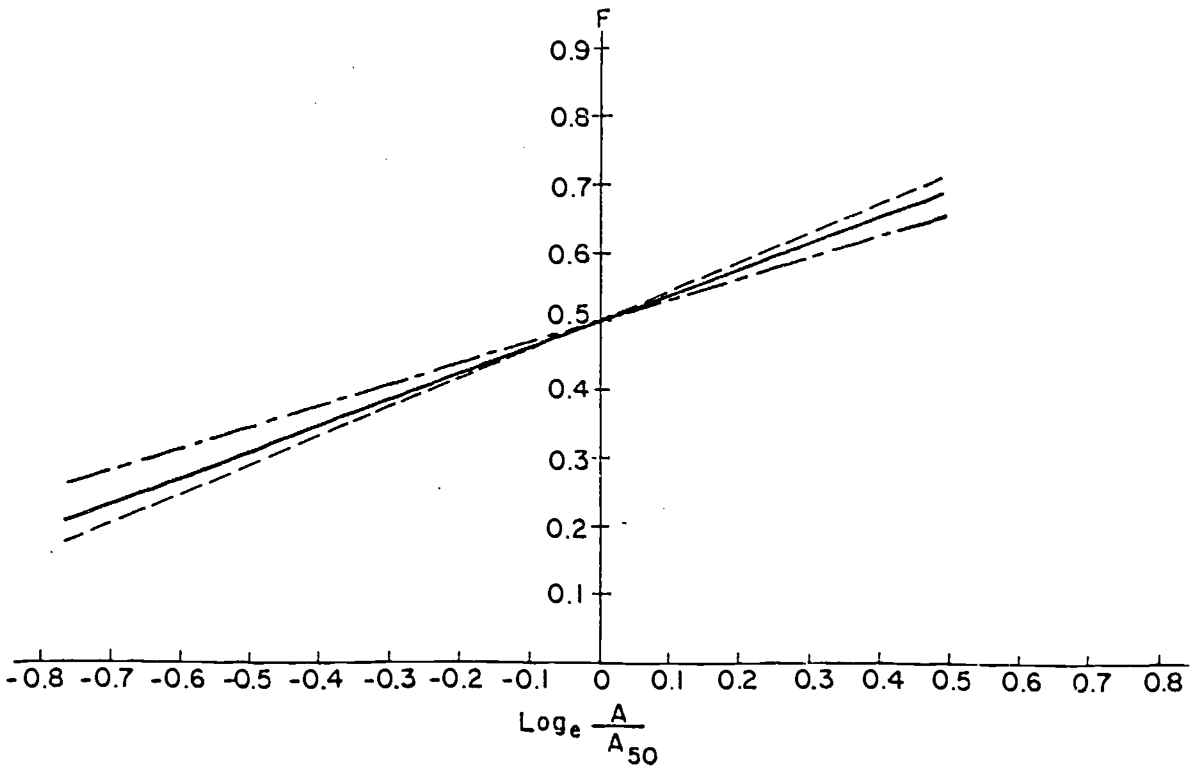

Figure 1. Annual Solar Fraction as a Function of $\log_e(A/A_{50})$

The collector area, A_{50}, required to supply 50 percent of the building heating load depends upon the building load as well as the quality of collectors used, and can be calculated from Equation (1).

$$A_{50} = \frac{A_S(UA)_L}{F_R' \overline{\tau\alpha} - F_R'U_L(Z)} \qquad (1)$$

where

A_S is a location dependent constant

$(UA)_L$ is the thermal conductance for the building but it also may include the water heating load,

$F_R'\overline{\tau\alpha}$ is the $F_R(\tau\alpha)_n$ (intercept) of the collector efficiency curve corrected for effective $\tau\alpha$ and heat exchanger in the collector loop

$F_R'U_L$ is the F_RU_L(slope) of the collector efficiency curve corrected for the effect of a heat exchanger in the collector loop,

Z is another location dependent constant

In Equation (1) once A_S and Z are known for a specific location, and with knowledge of $(UA)_L$ and the characteristics of the collector, the annual fraction can be determined from

$$F = 0.5 + c_2 \log_e(A/A_{50}).$$

The lines in Figure 1 are drawn so that the point $F = 0.5$, $\log_e(A/A_{50}) = 0$ is on the line. If however, a "best fit" curve is drawn through the calculated points of F and $\log_e(A/A_{50})$, the intercept is not always at 0.5. The general equation for the best fit line is

$$F = c_1 + c_2 \log_e(A/A_{50}) \qquad (2)$$

where

F is the annual fraction,

c_1 is the intercept on the $\log_e(A/A_{50}) = 0$ axis, and may be different from 0.5

c_2 is the slope of the line.

Values of c_1, c_2, A_S and Z for liquid and air-heating systems are listed on Table 2 for 170 cities in the United States and Canada. Included in the tables also are the latitudes and heating "degree-days" expressed in (°F·hr)/year.

An additional set of columns are given in Table 2 for domestic hot water systems. The form of the F-equation for systems that heat only domestic water needs is the same as Equation (2), however, A_{50} is determined by

$$A_{50} = \frac{A_D \; D \; \Delta T}{F_R' \overline{\tau\alpha} - F_R' U_L(Z)} \tag{3}$$

where

A_D and Z	are location dependent constants that are listed in the table
D	is the daily hot water demand, kgal/day
ΔT	is the difference between the temperature of water in the mains and set temperature of water in the conventional hot water tank; °F

EXAMPLE

Determine the annual solar fraction for a solar space and water heating system for a building in Fort Collins, Colorado. For convenience use a worksheet for the relative areas method as provided.

Answer

$F = \underline{0.73}$ for $A_c = 500\ ft^2$

$F = \underline{0.58}$ for $A_c = 300\ ft^2$

From the f-chart method the results were

$F = 0.68$ for $A_c = 500\ ft^2$

$F = 0.49$ for $A_c = 300\ ft^2$

The heat loss calculations for the building have been made and the overall $(UA)_L$ is 714 Btu/(hr•°F). Assume Lennox water heating collectors with $F_R(\tau\alpha)_n = 0.73$ and $F_RU_L = 0.54$ Btu/(hr·ft²·°F). Use the values in Table 2 for Denver, Colorado.

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SOLAR SYSTEM DATA

Building Owner Mr. & Mrs. John Sunbody

Address 136 Sunshine Ave. Fort Collins CO Ph. 482-0000

Contractor Solar Construction Co. Ph. 482-0001

Type of System (liquid, air, H/DHW, DWH) Liquid, H/DHW

Site and Building Data

1. Location: Nearest City Fort Collins Latitude 40.6°N
2. Building UA 714 Btu/(hr·°F)
3. DHW volume per day 80 gallons/day

Collector Data

4. Collector manufacturer Lennox
5. Collector Area, A_c = 500 ft^2
6. Collector efficiency data from manufacturer's information:
   (a) $F_R(\tau\alpha)$ 0.73
   (b) F_RU_L 0.54 Btu/(hr·ft²·°F)
7. Correction for fluid temperature basis
   (a) Case 1: (no correction)
      (i) $F_R(\tau\alpha)_n = F_R\tau\alpha$ (from line 6) 0.73
      (ii) $F_RU_L = F_RU_L$ (from line 6) 0.54 Btu/(hr·ft²·°F)

   (b) Case 2: $\frac{T_{in} + T_{out}}{2}$ (correction needed)

$$C_c = (\dot{m}c_p)_c = \left(\begin{matrix}\text{Vol flow}\\ \text{rate}\end{matrix}\right)(\text{density})\left(\begin{matrix}\text{time}\\ \text{conversion}\end{matrix}\right)\left(\begin{matrix}\text{specific}\\ \text{heat}\end{matrix}\right)$$

$$= \underline{10}\ \frac{\text{gal}}{\text{min}} \times 8.92\ \frac{\text{lb}}{\text{gal}} \times 60\ \frac{\text{min}}{\text{hr}} \times 0.9\ \frac{\text{Btu}}{\text{lb}\cdot{}^\circ\text{F}}$$

$$= \underline{4817}\ \text{Btu/(hr}\cdot{}^\circ\text{F)}$$

Correction Factor = $[\frac{1}{1 + \frac{F_R U_L A_c}{2C_c}}]$ = ________________

(i) $F_R(\tau\alpha)_n$ = $F_R\tau\alpha$(from line 6a) x (correction factor)

= ______________ x ________ = ________

(ii) $F_R U_L$ = $F_R U_L$(from line 6b) x (correction factor)

= ______________ x ________ = ________ Btu/(hr·ft^2·°F)

(c) Case 2: T_{out}(correction needed)

Correction Factor = $\frac{1}{1 + \frac{F_R U_L A_c}{C_c}}$ = __________

(i) $F_R(\tau\alpha)_n$ = $F_R(\tau\alpha)$(from line 6a) x (correction factor)

= __________ x __________ = __________

(ii) $F_R U_L$(from line 6b) x (correction factor)

= __________ x __________ = __________ Btu/(hr·ft^2·°F)

Heat Exchanger Factor (F_R'/F_R)

8. For air collectors $F_R'/F_R = 1$

9. For liquid collectors

(a) C_c(from line 7b) = 4817 Btu/(hr·°F)

(b) C_s = 15 x 8.34 x 60 x 1 = 7506 Btu/(hr·°F)

(c) Heat exchanger effectiveness = 0.75

(d) $x = \frac{C_c}{\varepsilon_{cs} C_{min}} = \frac{4817}{(0.75)(4817)} = 1.33$

(e) $y = \frac{A_c F_R U_L}{C_c} = \frac{(500)(.54)}{4817} = 0.06$

(f) $F_R'/F_R = \frac{1}{1 + y(x-1)}$ = 0.98

Corrections to Collector Parameters

10. Incident angle modifier

(a) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times 0.91$ (for two cover plates)

$= \_\_\_\_\_\_ \times 0.91 = \_\_\_\_\_\_$

(b) $F_R(\overline{\tau\alpha}) = F_R(\tau\alpha)_n \times 0.93$ (for one cover plate)

$= \underline{0.73} \times 0.93 = \underline{0.68}$

11. (a) $F_R'\overline{\tau\alpha} = \dfrac{0.68}{\text{line 10a or 10b}} \times \dfrac{.98}{\text{line 8 or 9f}} = \underline{0.67}$

(b) $F_R'U_L = \dfrac{0.54}{\text{line 7a(ii) or 7b(ii) or 7c(ii)}} \times \dfrac{.98}{\text{line 8 or 9f}} = \underline{0.53}$ Btu/(hr·°F)

List c_1, c_2, A_S, A_D, Z from Table 14-2

12. A_S or A_D = $\underline{.197}$ Z = $\underline{.241}$ c_1 = $\underline{.531}$ c_2 = $\underline{.301}$

For Solar Heating and DHW Systems:

13. $A_{50} = \dfrac{A_S(UA)_L}{F_R'\overline{\tau\alpha} - F_R'U_L(Z)}$

$A_{50} = \dfrac{(.197)\quad(714)}{(0.67) - (.53)(.241)} = \underline{259}\ ft^2$

14. A_c/A_{50} = $\underline{500/254}$ = $\underline{1.93}$

15. $\log_e(A_c/A_{50})$ = $\underline{0.66}$

16. $F = c_1 + c_2 \log_e(A/A_{50})$

$= \underline{.531} + \underline{(.301)(0.66)} = 0.73$

17. A_c/A_{50} = 300/259 = 1.16

18. $\mathrm{Log}_e(A_c/A_{50})$ = 0.15

19. F = $\underline{.531}$ + (.301)(.15) = 0.58 ANSWER

Table 2. Constants for Relative Areas Method

CITY	ST	LAT. (DEG.)	D-H (FHR/YR)	LIQUID SYSTEM A_s $(\frac{°F \cdot ft^2 \cdot Hr}{Btu})$	LIQUID SYSTEM Z	LIQUID SYSTEM C_1	LIQUID SYSTEM C_2	AIR SYSTEM A_s $(\frac{°F \cdot ft^2 \cdot Hr}{Btu})$	AIR SYSTEM Z	AIR SYSTEM C_1	AIR SYSTEM C_2	DOMESTI[illegible]T WATER ONLY A_D $\frac{ft^2 \cdot D}{°F\ kgal}$	DOMESTI[illegible]T WATER ONLY Z $(\frac{°F \cdot ft^2 \cdot Hr}{Btu})$	DOMESTI[illegible]T WATER ONLY C_1	DOMESTI[illegible]T WATER ONLY C_2
Annette	AK	55.0	172607	.309	.390	.510	.257	.289	.316	.514	.284	5.007	.392	.530	.309
Bethel	AK	60.5	316702	.485	.365	.508	.255	.453	.289	.511	.284	4.409	.417	.535	.314
Fairbanks	AK	64.5	342696	.638	.412	.506	.226	.595	.331	.505	.249	4.288	.407	.538	.322
Matanuska	AK	61.3	260371	.483	.413	.503	.231	.450	.330	.502	.253	4.818	.418	.539	.322
Birmingham	AL	33.3	68248	.161	.256	.529	.283	.152	.211	.548	.319	3.370	.211	.545	.341
Fort Smith	AR	35.2	80060	.195	.263	.528	.284	.184	.217	.547	.322	3.412	.217	.543	.338
Little Rock	AR	34.4	77255	.192	.268	.528	.282	.181	.221	.547	.320	3.421	.219	.543	.337
Page	AZ	36.4	129119	.149	.172	.535	.312	.140	.141	.545	.335	2.423	.177	.552	.356
Phoenix	AZ	33.3	37249	.063	.163	.536	.309	.059	.133	.543	.328	2.398	.134	.558	.367
Tucson	AZ	32.1	43199	.070	.159	.540	.314	.066	.130	.551	.338	2.396	.141	.557	.365
Yuma	AZ	32.4	24141	.046	.176	.530	.303	.043	.141	.533	.322	2.499	.132	.559	.369
Davis	CA	38.3	60047	.137	.269	.516	.257	.129	.220	.528	.286	3.066	.204	.540	.331
Fresno	CA	36.5	62665	.130	.243	.519	.262	.123	.199	.531	.288	2.957	.188	.545	.340
Inyokern	CA	35.4	56878	.077	.140	.534	.307	.072	.115	.541	.325	2.052	.121	.559	.369
Los Angeles	CA	33.6	43657	.054	.197	.535	.305	.051	.154	.544	.330	2.834	.182	.551	.354
Pasadena	CA	34.1	40647	.060	.201	.535	.308	.057	.159	.546	.334	2.916	.183	.550	.353
Riverside	CA	33.6	46056	.065	.173	.538	.312	.061	.142	.551	.336	2.614	.165	.554	.359
Sacramento	CA	38.3	68225	.133	.255	.518	.259	.125	.206	.526	.286	3.028	.197	.543	.336
San Diego	CA	32.4	36161	.053	.211	.536	.309	.050	.168	.547	.336	3.139	.200	.548	.347
San Francisco	CA	37.5	73911	.082	.227	.530	.310	.077	.180	.542	.340	3.232	.221	.543	.338
San Jose	CA	37.2	55967	.101	.254	.520	.270	.095	.206	.531	.294	3.336	.226	.541	.334
Santa Maria	CA	34.5	71207	.066	.183	.529	.310	.062	.146	.538	.334	2.600	.180	.551	.354
Boulder	CO	40.0	132960	.196	.241	.531	.301	.184	.196	.544	.334	3.295	.242	.540	.333
Denver	CO	39.5	144377	.175	.197	.538	.316	.165	.156	.549	.347	2.639	.197	.548	.348
Grand Junction	CO	39.1	135334	.196	.201	.531	.303	.185	.165	.544	.331	2.661	.193	.549	.349
Grand Lake	CO	40.2	259248	.262	.230	.526	.302	.246	.185	.537	.332	2.876	.256	.537	.327
Pueblo	CO	38.2	129448	.164	.184	.537	.316	.154	.147	.548	.345	2.547	.184	.551	.353
Hartford	CT	41.6	152395	.286	.286	.526	.287	.269	.232	.543	.328	3.653	.273	.536	.323
Washington	DC	38.5	101375	.237	.307	.520	.271	.224	.248	.533	.307	3.829	.260	.537	.325
Apalachicola	FL	29.5	31391	.066	.195	.538	.311	.062	.159	.550	.339	2.921	.168	.553	.358
Gainesville	FL	29.4	25941	.058	.202	.535	.306	.054	.164	.544	.334	3.057	.171	.553	.358
Jacksonville	FL	30.3	31843	.076	.217	.537	.309	.072	.177	.551	.341	3.292	.189	.550	.352
Key West	FL	24.3	1533	.004	.172	.544	.326	.004	.143	.562	.359	2.993	.145	.557	.365
Miami	FL	25.5	5137	.014	.160	.542	.333	.013	.132	.562	.368	2.919	.149	.556	.364
Pensacola	FL	30.3	37866	.093	.230	.534	.299	.087	.188	.548	.331	3.215	.187	.550	.351
Tallahassee	FL	30.3	37510	.076	.192	.535	.305	.072	.156	.545	.331	3.045	.178	.550	.352
Tampa	FL	27.6	17233	.036	.179	.536	.318	.033	.146	.544	.346	2.873	.156	.555	.363
Atlanta	GA	33.4	74282	.162	.240	.529	.289	.153	.198	.547	.324	3.338	.214	.545	.343
Griffin	GA	33.2	67201	.141	.228	.533	.291	.133	.187	.550	.323	3.142	.201	.548	.347
Macon	GA	32.4	53756	.122	.226	.536	.300	.115	.186	.553	.334	3.189	.192	.549	.350
Savannah	GA	32.1	46844	.108	.228	.534	.298	.102	.186	.550	.331	3.265	.193	.549	.351
Hilo	HI	19.4	0	.000	.000	.000	.000	.000	.000	.000	.000	3.470	.185	.550	.352
Honolulu	HI	21.2	0	.000	.000	.000	.000	.000	.000	.000	.000	2.617	.132	.558	.367
Ames	IA	42.0	163776	.312	.284	.525	.281	.295	.231	.542	.320	3.567	.271	.537	.325
Des Moines	IA	41.3	161033	.327	.295	.522	.269	.308	.243	.538	.308	3.495	.262	.537	.324
Boise	ID	43.3	139417	.238	.277	.515	.259	.223	.225	.524	.290	3.183	.237	.536	.323
Pocatello	ID	42.6	169513	.242	.248	.522	.278	.228	.197	.531	.308	2.960	.229	.540	.331
Twin Falls	ID	40.4	151774	.263	.288	.518	.264	.247	.233	.529	.296	3.458	.260	.534	.319
Chicago	IL	41.6	147047	.314	.303	.522	.276	.296	.247	.540	.315	3.716	.270	.535	.321
Lemont	IL	41.4	147047	.316	.305	.522	.275	.298	.250	.540	.315	3.730	.271	.535	.321
Peoria	IL	40.4	146345	.315	.308	.519	.265	.296	.253	.535	.304	3.591	.263	.536	.322
Fort Wayne	IN	41.0	149012	.319	.315	.518	.262	.301	.261	.536	.302	3.651	.270	.534	.318
Indianapolis	IN	39.4	133847	.325	.340	.518	.257	.306	.279	.532	.295	3.857	.276	.532	.314
Dodge City	KS	37.5	121103	.176	.196	.534	.307	.166	.162	.549	.337	2.699	.191	.549	.350
Manhattan	KS	39.1	124369	.242	.269	.524	.282	.227	.218	.538	.316	3.411	.238	.541	.333
Wichita	KS	37.4	112481	.206	.237	.530	.293	.195	.189	.545	.327	3.103	.212	.546	.343
Lexington	KY	38.0	113495	.227	.268	.523	.271	.215	.216	.537	.303	3.162	.221	.540	.331

Table 2 (continued)

CITY	ST	LAT. (DEG.)	D-H (FHR/YR)	LIQUID SYSTEM A_s $(\frac{°F\cdot ft^2\cdot Hr}{Btu})$	LIQUID SYSTEM Z	LIQUID SYSTEM C_1	LIQUID SYSTEM C_2	AIR SYSTEM A_s $(\frac{°F\cdot ft^2\cdot Hr}{Btu})$	AIR SYSTEM Z	AIR SYSTEM C_1	AIR SYSTEM C_2	DOMESTIC HOT WATER ONLY A_D $\frac{ft^2\cdot D}{°F\ kgal}(\frac{°F\cdot ft^2\cdot Hr}{Btu})$	DOMESTIC HOT WATER ONLY Z	DOMESTIC HOT WATER ONLY C_1	DOMESTIC HOT WATER ONLY C_2
ouisville	KY	38.1	111353	.266	.311	.521	.267	.252	.253	.539	.307	3.690	.257	.536	.323
ake Charles	LA	30.1	35015	.087	.231	.534	.302	.082	.189	.549	.336	3.228	.187	.549	.350
lew Orleans	LA	29.6	33238	.098	.276	.527	.288	.093	.224	.544	.326	3.896	.225	.542	.336
ihreveport	LA	32.3	52415	.136	.255	.532	.294	.128	.209	.550	.333	3.407	.204	.546	.343
mherst	MA	42.2	157825	.379	.370	.516	.255	.357	.302	.528	.287	4.277	.323	.528	.308
Blue Hill	MA	42.1	152809	.310	.320	.523	.276	.293	.257	.539	.316	3.956	.299	.532	.316
Boston	MA	42.2	135215	.321	.342	.521	.269	.304	.278	.538	.310	4.198	.302	.531	.314
Lynn	MA	42.3	135215	.341	.370	.516	.255	.322	.303	.528	.289	4.277	.310	.527	.304
Natick	MA	42.2	[illegible]	.303	.307	.522	.275	[illegible]	.248	.537	.313	3.890	.285	.533	.317
Annapolis	MD	38.6	109146	.239	.292	.522	.278	.225	.239	.538	.317	3.675	.256	.538	.327
Baltimore	MD	39.1	113491	.246	.287	.523	.280	.232	.235	.539	.318	3.643	.252	.539	.329
Silver Hill	MD	38.5	101064	.227	.280	.524	.280	.215	.225	.542	.319	3.596	.244	.540	.332
Caribou	ME	46.5	234406	.385	.309	.521	.272	.362	.249	.533	.303	3.805	.320	.529	.309
Portland	ME	43.4	175462	.285	.281	.525	.282	.268	.226	.539	.318	3.505	.275	.535	.321
Detroit	MI	42.1	154049	.361	.351	.517	.254	.340	.291	.532	.291	3.928	.294	.529	.309
East Lansing	MI	42.4	165697	.385	.365	.517	.253	.363	.298	.529	.286	4.071	.313	.527	.305
Lansing	MI	42.5	165689	.368	.347	.519	.260	.348	.284	.533	.296	3.954	.301	.529	.309
Sault St. Marie	MI	46.3	217151	.363	.319	.517	.261	.343	.256	.528	.291	3.763	.317	.527	.304
Columbia	MO	38.6	121103	.245	.275	.524	.276	.230	.225	.539	.312	3.359	.236	.540	.331
Kansas City	MO	39.2	123859	.257	.274	.525	.277	.243	.220	.541	.314	3.357	.234	.541	.332
St. Louis	MO	38.5	113993	.253	.285	.522	.271	.240	.232	.540	.308	3.505	.240	.539	.330
Springfield	MO	37.1	109672	.175	.249	.526	.226	.167	.207	.536	.248	2.951	.215	.546	.302
Duluth	MN	46.5	234136	.397	.323	.518	.264	.374	.260	.529	.297	3.749	.315	.530	.312
Minn. St. Paul	MN	44.5	195807	.398	.325	.519	.263	.376	.265	.535	.302	3.765	.298	.532	.316
St. Cloud	MN	45.3	212831	.349	.274	.525	.284	.328	.223	.539	.317	3.415	.277	.535	.321
Jackson	MS	32.2	55195	.139	.257	.530	.286	.131	.210	.547	.322	3.395	.204	.546	.343
Billings	MT	45.5	174353	.259	.256	.527	.289	.245	.204	.540	.322	3.139	.245	.539	.329
Glasgow	MT	48.1	215906	.294	.237	.527	.287	.277	.192	.539	.316	2.952	.242	.540	.332
Great Falls	MT	47.3	186001	.268	.259	.524	.283	.251	.211	.536	.313	3.202	.252	.537	.326
Summit	MT	48.2	255070	.393	.349	.513	.255	.367	.282	.521	.287	4.009	.348	.524	.299
Ashville	NC	35.3	101681	.177	.243	.527	.289	.166	.196	.539	.322	3.203	.221	.544	.340
Cape Hattaras	NC	35.2	65545	.117	.208	.531	.298	.111	.167	.543	.325	2.863	.183	.551	.354
Charlotte	NC	35.1	77225	.159	.229	.532	.293	.150	.190	.550	.327	3.178	.205	.547	.346
Greensboro	NC	36.1	91801	.189	.252	.525	.284	.179	.207	.544	.321	3.393	.229	.543	.338
Grnvle-Sptnbrg	NC	34.5	75907	.162	.237	.531	.289	.153	.195	.548	.323	3.243	.209	.546	.344
Raleigh	NC	35.5	84335	.161	.231	.530	.300	.152	.184	.545	.334	3.306	.216	.546	.343
Raleigh-Durham	NC	35.5	84333	.173	.241	.526	.291	.164	.198	.545	.326	3.388	.221	.545	.341
Bismarck	ND	46.5	217056	.327	.260	.524	.281	.307	.211	.537	.314	3.149	.260	.538	.327
Fargo	ND	46.5	222497	.415	.319	.519	.264	.391	.257	.530	.300	3.657	.300	.533	.317
Lincoln	NE	40.5	140806	.256	.257	.527	.285	.242	.212	.545	.323	3.328	.242	.540	.332
North Omaha	NE	41.2	158687	263	.249	.528	.292	.249	.199	.543	.328	3.231	.237	.542	.335
Atlantic City	NJ	39.3	112629	.218	.261	.525	.287	.206	.213	.541	.320	3.449	.242	.540	.332
Trenton	NJ	40.1	118727	.243	.276	.523	.282	.229	.227	.541	.320	3.562	.253	.539	.329
Albuquerque	NM	35.0	103006	.133	.167	.538	.318	.125	.136	.549	.344	2.332	.164	.554	.360
Ely	NV	39.2	185590	.197	.191	.534	.310	.186	.156	.546	.336	2.536	.206	.547	.345
Las Vegas	NV	36.1	65015	.102	.163	.539	.312	.096	.133	.550	.334	2.377	.144	.557	.365
Reno	NV	39.3	144521	.158	.189	.533	.303	.149	.154	.543	.328	2.511	.192	.548	.348
Albany	NY	42.4	165311	.328	.322	.512	.256	.307	.255	.519	.282	3.829	.292	.531	.313
Binghampton	NY	42.1	174835	.371	.351	.517	.256	.351	.286	.530	.292	3.987	.309	.529	.309
Ithaca	NY	42.3	169246	.407	.387	.518	.251	.385	.319	.529	.282	4.281	.332	.525	.301
New York	NY	40.5	115462	.326	.369	.520	.266	.306	.304	.533	.301	4.503	.310	.530	.311
Rochester	NY	43.1	161249	.348	.338	.518	.259	.329	.275	.532	.297	3.853	.292	.530	.311
Schenectady	NY	42.5	163610	.409	.385	.521	.265	.386	.317	.531	.298	4.646	.344	.530	.311
Syracuse	NY	43.1	160264	.386	.371	.519	.256	.364	.304	.530	.290	4.126	.313	.527	.304
Cleveland	OH	41.2	147697	.367	.372	.516	.247	.346	.307	.526	.279	4.059	.301	.526	.303
Columbus	OH	40.0	135840	.326	.348	.515	.252	.307	.286	.530	.290	3.903	.284	.530	.310
Dayton	OH	39.5	135377	.294	.306	.520	.266	.277	.252	.536	.304	3.580	.259	.535	.321

Table 2 (continued)

CITY	ST	LAT. (DEG.)	D-H (FHR/YR)	LIQUID SYSTEM A_s $(\frac{°F \cdot ft^2 \cdot Hr}{Btu})$	LIQUID SYSTEM Z	LIQUID SYSTEM C_1	LIQUID SYSTEM C_2	AIR SYSTEM A_s $(\frac{°F \cdot ft^2 \cdot Hr}{Btu})$	AIR SYSTEM Z	AIR SYSTEM C_1	AIR SYSTEM C_2	DOMESTIC HOT WATER ONLY A_D $\frac{ft^2 \cdot D}{°F\ kgal}$	DOMESTIC HOT WATER ONLY Z $(\frac{°F \cdot ft^2 \cdot Hr}{Btu})$	DOMESTIC HOT WATER ONLY C_1	DOMESTIC HOT WATER ONLY C_2
Put-in-Day	OH	41.4	142030	.376	.369	.519	.254	.354	.303	.532	.289	3.946	.288	.526	.303
Oklahoma City	OK	35.2	88676	.159	.206	.535	.304	.151	.169	.552	.336	2.885	.190	.549	.349
Stillwater	OK	36.1	87143	.180	.237	.529	.290	.170	.194	.546	.322	3.173	.207	.545	.342
Tulsa	OK	36.1	88315	.196	.250	.529	.291	.186	.204	.548	.327	3.320	.214	.544	.340
Astoria	OR	46.1	127078	.222	.359	.509	.242	.208	.291	.518	.274	4.422	.333	.521	.293
Corvallis	OR	44.3	116497	.242	.378	.508	.224	.228	.302	.513	.253	4.033	.301	.518	.286
Medford	OR	42.2	118319	.235	.331	.505	.229	.220	.264	.512	.260	3.500	.256	.525	.300
Portland	OR	45.4	115001	.269	.401	.517	.243	.253	.324	.521	.270	4.645	.334	.522	.295
Philadelphia	PA	39.5	116755	.247	.283	.523	.279	.232	.232	.539	.317	3.610	.253	.539	.329
Pittsburgh	PA	40.3	126665	.278	.306	.519	.268	.262	.252	.536	.306	3.700	.262	.535	.322
State College	PA	40.5	147169	.352	.357	.518	.257	.332	.293	.532	.293	4.095	.304	.529	.310
Newport	RI	41.3	139294	.258	.295	.524	.281	.243	.239	.540	.322	3.741	.275	.535	.321
Charleston	SC	32.5	48792	.112	.221	.537	.305	.105	.181	.554	.339	3.243	.195	.549	.350
Rapid City	SD	44.1	176279	.233	.225	.532	.300	.218	.182	.543	.331	2.917	.225	.543	.338
Chattanooga	TN	35.0	84117	.195	.267	.526	.279	.185	.221	.547	.320	3.474	.226	.542	.336
Memphis	TN	35.0	77443	.188	.265	.528	.280	.177	.218	.546	.317	3.342	.211	.544	.338
Nashville	TN	36.1	88703	.232	.301	.522	.266	.219	.248	.542	.305	3.626	.239	.538	.327
Oak Ridge	TN	36.0	94658	.233	.300	.520	.265	.221	.249	.541	.305	3.709	.248	.537	.326
Abilene	TX	32.3	62634	.120	.198	.537	.307	.113	.163	.553	.337	2.867	.174	.552	.356
Amarillo	TX	35.1	100385	.143	.183	.536	.313	.134	.150	.549	.341	2.611	.176	.552	.356
Big Spring	TX	32.2	62182	.121	.200	.537	.305	.114	.163	.552	.336	2.899	.179	.550	.352
Brownsville	TX	25.6	15600	.046	.219	.533	.307	.043	.179	.548	.342	3.182	.168	.552	.355
Corpus Christi	TX	27.5	22318	.061	.240	.527	.301	.057	.191	.535	.331	3.147	.170	.551	.353
Dallas	TX	32.5	54952	.132	.235	.534	.298	.124	.193	.549	.331	3.219	.189	.548	.348
El Paso	TX	31.5	64798	.097	.155	.541	.316	.092	.127	.551	.337	2.330	.145	.557	.366
Fort Worth	TX	32.5	57720	.119	.209	.535	.303	.112	.172	.549	.333	2.927	.176	.551	.352
Houston	TX	29.6	34412	.092	.245	.530	.295	.086	.198	.542	.327	3.260	.183	.549	.349
Midland	TX	31.6	62182	.115	.190	.537	.308	.108	.156	.551	.336	2.753	.172	.553	.357
Port Arthur	TX	29.6	36428	.099	.255	.530	.291	.093	.207	.545	.326	3.447	.196	.547	.346
San Antonio	TX	29.3	37103	.084	.211	.538	.309	.079	.173	.552	.339	3.042	.174	.551	.353
Salt Lake City	UT	40.5	143591	.246	.271	.519	.269	.231	.218	.530	.301	3.244	.237	.538	.328
Mt. Weather	VA	39.0	136034	.257	.280	.525	.285	.242	.226	.541	.324	3.636	.266	.537	.326
Norfolk	VA	36.5	83707	.175	.254	.527	.289	.166	.205	.544	.325	3.397	.225	.544	.339
Richmond	VA	37.5	94530	.206	.267	.523	.280	.195	.219	.542	.317	3.502	.234	.542	.335
Prusser	WA	46.2	134578	.235	.291	.510	.240	.219	.232	.515	.266	3.149	.237	.532	.316
Pullman	WA	46.4	158974	.261	.303	.516	.252	.245	.244	.524	.283	3.398	.266	.529	.310
Richland	WA	46.2	117406	.268	.349	.504	.224	.251	.281	.511	.255	3.644	.262	.526	.303
Seattle	WA	47.3	106178	.251	.413	.509	.221	.235	.335	.510	.243	4.551	.333	.517	.285
Spokane	WA	47.4	164039	.295	.310	.513	.249	.277	.251	.526	.282	3.505	.272	.527	.305
Green Bay	WI	44.3	194344	.387	.336	.519	.260	.364	.272	.530	.296	3.882	.308	.531	.313
Madison	WI	43.1	185520	.348	.310	.522	.270	.329	.248	.534	.306	3.658	.286	.533	.318
Milwaukee	WI	42.6	178649	.350	.325	.518	.261	.331	.262	.532	.298	3.723	.290	.532	.315
Parkersburg	WV	39.2	115601	.301	.352	.519	.258	.286	.285	.533	.296	3.996	.278	.531	.313
Lander	WY	42.5	188879	.211	.193	.536	.313	.198	.157	.547	.340	2.565	.205	.547	.346
Laramie	WY	41.2	212137	.243	.221	.534	.309	.230	.177	.549	.342	2.907	.240	.541	.334
Edmonton	AT	53.3	246430	.376	.300	.517	.267	.355	.238	.528	.297	3.632	.313	.531	.313
Lethbridge	AT	49.4	207455	.300	.274	.520	.273	.283	.221	.532	.303	3.316	.275	.534	.319
Vancouver	BC	48.6	132357	.354	.477	.533	.257	.333	.404	.515	.244	5.347	.403	.526	.299
Churchill	MA	58.5	401471	.542	.322	.517	.276	.508	.262	.530	.309	3.735	.383	.530	.308
Winnipeg	MA	49.5	256296	.405	.286	.522	.276	.382	.231	.534	.307	3.446	.301	.532	.315
Moncton	NB	46.1	209447	.431	.385	.516	.251	.407	.310	.522	.279	4.484	.366	.530	.312
St. Johns	NF	47.3	215785	.472	.442	.525	.268	.445	.365	.520	.276	5.414	.434	.548	.341
Kapuskasing	OT	49.3	277727	.538	.376	.517	.262	.504	.310	.526	.290	4.410	.389	.535	.320
Ottawa	OT	45.3	209638	.391	.316	.522	.269	.368	.258	.536	.304	3.747	.310	.530	.312
Toronto	OT	43.4	163844	.391	.382	.518	.256	.368	.312	.526	.287	4.321	.336	.526	.304
Montreal	QU	45.3	196871	.471	.398	.514	.244	.440	[illegible]	.516	.268	4.368	.354	.526	.302

15. ECONOMIC ANALYSIS

(Module 15, Installation Manual; Module 8, Design Manual)

The material presented in Module 8 of the Design Manual represents a very simple approach to the economic analysis of a solar system. It omits a great deal of detail, such as insurance, property tax, operating and maintenance costs, and income tax savings. The procedure explained in the Installation manual omits present worth discounting. Therefore, we suggest that the materials in both manuals be replaced by the module included herewith. The attached module includes most of the information in the Installation manual and presents a detailed life cycle cost analysis procedure for residential solar systems.

INTRODUCTION

The major portion of the cost of heating a house with a conventional heating system is the cost of energy used by the system. A significant portion of the cost of heating a house with a solar system includes payment for solar hardware as well as energy used by the auxiliary unit in the solar system. While capital investment in a conventional heating system is usually less than $2,000, the capital investment in a solar heating system is many times that amount.

Economic analysis of a solar system involves comparison of the capital and operating costs of a solar system with the operating costs of a conventional system. Among many methods available, a method of life-cycle cost analysis for annual and cumulative cash flows, and present worth of savings realizable with a solar system compared to a non-solar system are explained in this module. By making repeated life-cycle cost analyses for different system sizes for a given building, it is possible to determine the most economical solar system based on either minimum installation and operating costs for the system over a preselected number of years, or the maximum savings realizable with the solar system when compared to a non-solar system over a preselected number of years.

OBJECTIVES

The objective of this module is to describe the life-cycle cost method of economic analysis to compare solar and non-solar systems. The trainee should be able to use the worksheets provided in this module to:

1. Determine the annual cash flows and present worth of savings.
2. Establish the economic feasibility of a solar system.

SOLAR SYSTEM COSTS

The total cost of a solar heating system, over the life of the system, includes (1) capital cost, (2) fuel cost for the auxiliary unit, and (3) operating and maintenance (O and M) costs. With a non-solar heating system the capital and O and M costs are small but fuel costs are high (and rising). A solar system has large capital costs, lower fuel costs, and O and M costs. To decide whether a solar system will save or lose money compared to a non-solar system, an economic comparison is necessary. The economic analysis presented in this module is the life-cycle cost approach.

The yearly cash flow for a residential solar heating system is:

$$\begin{aligned}\text{Yearly cost with solar} &= \text{Mortgage payment} + \text{Auxiliary fuel cost} + \text{Property tax increase} + \text{Insurance premium} \\ &\quad + \text{Operating costs} + \text{Maintenance cost} - \text{Income tax savings for interest and taxes paid}\end{aligned} \qquad [15\text{-}1]$$

whereas for a non-solar system,

$$\text{Yearly cost for non-solar} = \text{Fuel cost} + \text{Operating and maintenance costs} \qquad [15\text{-}2]$$

In commercial buildings there are other factors such as depreciation of equipment and salvage value to be considered.

The sum of the yearly cash flows over the "life" of the system can be construed as the life-time cost of the system, and the costs of the solar and non-solar systems can be compared over an equal lifetime of n years, to determine which system would be more expensive. Cash flow calculations should include inflation, with fuel costs perhaps increasing more rapidly than costs of general goods and services (at least in the near term). The use of different inflation factors for the items in

Equation [15-1] or [15-2] in effect gives more weight to some cost items over others, say fuel costs over mortgage payments as an example, particularly if mortgage payment is fixed and fuel cost rises.

Because the sum of annual cash flows for both solar and non-solar systems would in effect add different value dollars each year as a consequence of inflation, a more appropriate economic comparison is made on the basis of present worth, which discounts future expenses to present dollars. Hence, when the present worth of future annual expenses are added, equivalent value dollars are being added. When inflation and discount factors are taken into consideration in a life-cycle cost analysis, Equations [15-1] and [15-2] may be rewritten as follows:

$$C_T(\text{solar}) = (AC_a)E_1 + C_oE_o + C_mE_m + (1-F)Lc_fE_f \qquad [15\text{-}3]$$

and

$$C_{TC}(\text{non-solar}) = C_{oc}E_o + C_{mc}E_m + Lc_fE_f \qquad [15\text{-}4]$$

where A is the collector area, ft^2

C_T is the total life-cycle cost of the solar system, \$

C_{TC} is the total life-cycle cost of the non-solar system, \$

C_a is the installed cost of the solar system per unit collector area, $\$/ft^2$

C_o is the first year operating cost for the solar system, \$/yr

C_{oc} is the first year operating cost for the non-solar system, \$/yr

C_m is the first year maintenance cost for the solar system, \$/yr

C_{mc} is the first year maintenance cost for the non-solar system, \$/yr

c_f is the first year fuel cost per unit of delivered heat, \$/MMBtu

E_1 is an economic factor which accounts for downpayment, mortgage interest rate, insurance rate, property tax rate, income tax saving, inflation rate, and market discount rate

E_o is an economic factor which accounts for inflation rate of operating cost and market discount rate

E_m is an economic factor which accounts for inflation rate of maintenance cost and market discount rate

E_f is an economic factor which accounts for fuel inflation rate and market discount rate

f is the fraction of annual heat provided by the solar system

L is an annual heating load for the building, MMBtu

The economic factors, E_o, E_m, and E_f are the sums of annual compounded inflation factors discounted annually to present worth. The present worth of an annuity (first year cost) over a life time of n years inflated at a constant rate and discounted at a constant rate can be written as:

$$P/X\ (d,r,n) = \frac{(1+d)^n - (1+r)^n}{(1+d)^n(d-r)} \text{ for } d \neq r \qquad [15\text{-}5]$$

and

$$P/X\ (d,r,n) = n/(1+r) \quad \text{for } d = r \qquad [15\text{-}6]$$

where P is the present value of an annuity over n years

X is the first year cost

d is the discount rate

r is the inflation rate

n is the years of analysis or life of the system

The notation (d,r,n) indicates that the value of P/X refers to values of d, r, and n, placed in the appropriate terms in Equations [15-5] and [15-6]. Tables of P/X values are provided in this module for an appropriate range of d, r, and n in Tables 15-1 through 15-6.

The economic factors can now be expressed as:

$$E_o = P/X\ (d,r_o,n) \text{ years} \qquad [15\text{-}7]$$

$$E_m = P/X\ (d,r_m,n) \text{ years} \qquad [15\text{-}8]$$

$$E_f = P/X\ (d,r_f,n) \text{ years} \qquad [15\text{-}9]$$

Table 15-1

Values of P/X (d, r, n) for Discount Rate of 0 Percent

Years	Annual Rate of Increase					
	0	3	6	8	10	12
10	10.0	11.464	13.181	14.487	15.937	17.549
11	11.0	12.808	14.972	16.645	18.531	20.655
12	12.0	14.192	16.870	18.977	21.384	24.133
13	13.0	15.618	18.882	21.495	24.523	28.029
14	14.0	17.086	21.015	24.215	27.975	32.393
15	15.0	18.599	23.276	27.152	31.772	37.280
16	16.0	20.157	25.673	30.324	35.950	42.753
17	17.0	21.762	28.213	33.750	40.545	48.884
18	18.0	23.414	30.906	37.450	45.599	55.750
19	19.0	25.117	33.760	41.446	51.159	63.440
20	20.0	26.870	36.786	45.762	57.275	72.052
21	21.0	28.676	39.993	50.423	64.002	81.699
22	22.0	30.537	43.392	55.457	71.403	92.503
23	23.0	32.453	46.996	60.893	79.543	104.603
24	24.0	34.426	50.816	66.765	88.497	188.155
25	25.0	36.459	54.865	73.106	98.347	133.334
26	26.0	38.553	59.156	79.954	109.182	150.334
27	27.0	40.710	63.706	87.351	121.100	169.374
28	28.0	42.931	68.528	95.339	134.210	190.699
29	29.0	45.219	73.640	103.966	148.631	214.583
30	30.0	47.575	79.058	113.283	164.494	241.333

Table 15-2

Values of P/X (d, r, n) for Discount Rate of 4 Percent

Years	Annual Rate of Increase					
	0	3	6	8	10	12
10	8.111	9.210	10.492	11.462	12 537	13.727
11	8.760	10.083	11.655	12.865	14.222	15.845
12	[illegible]85	10.947	12.841	14.321	16.004	17.91[illegible]
13	9.986	11.804	14.049	15.833	17.889	20.25[illegible]
14	10.563	12.652	15.281	17.404	19.883	22.777
15	11.118	13.492	16.536	19.035	21.991	25.491
16	11.652	14.323	17.816	20.728	24.222	28.413
17	12.166	15.147	19.120	22.487	26.580	31.561
18	12.659	15.963	20.449	24.314	29.076	34.950
19	13.134	16.771	21.804	26.210	31.714	38.600
20	13.590	17.571	23.185	28.180	34.506	42.531
21	14.029	18.364	24.592	30.225	37.458	46.764
22	14.451	19.149	26.027	32.349	40.581	51.322
23	14.857	19.926	27.489	34.555	43.883	56.232
24	15.247	20.696	28.979	36.846	47.377	61.519
25	15.622	21.459	30.498	39.224	51.071	67.213
26	15.983	22.214	32.046	41.695	54.979	73.344
27	16.330	22.962	33.623	44.260	59.113	79.448
28	16.663	23.703	35.232	46.924	63.485	87.059
29	16.984	24.436	36.871	49.690	69.109	94.718
30	17.292	25.163	38.541	52.563	73.000	102.965

Table 15-3

Values of P/X (d, r, n) for Discount Rate of 6 Percent

Years	Annual Rate of Increase					
	0	3	6	8	10	12
10	7.360	8.319	9.434	10.277	11.208	12.238
11	7.887	9.027	10.377	11.414	12.575	13.874
12	8.384	9.715	11.321	12.573	13.993	15.603
13	8.853	10.383	12.264	13.753	15.464	17.430
14	9.295	11.033	13.208	14.956	16.991	19.360
15	9.712	11.664	14.151	16.182	18.575	21.399
16	10.106	12.277	15.094	17.430	20.220	23.553
17	10.477	12.873	16.038	18.703	21.926	25.830
18	10.828	13.452	16.981	19.999	23.697	28.236
19	11.158	14.015	17.925	21.320	25.535	30.777
20	11.470	14.562	18.868	22.665	27.442	33.463
21	11.764	15.093	19.811	24.036	29.421	36.300
22	12.042	15.609	20.755	25.433	31.474	39.298
23	12.303	16.111	21.698	26.857	33.605	42.466
24	12.550	16.598	22.642	28.307	35.817	45.813
25	12.783	17.072	23.585	29.784	38.112	49.350
26	13.003	17.532	24.528	31.290	40.493	53.087
27	13.211	17.979	25.472	32.823	42.965	57.035
28	13.406	18.414	26.415	34.386	45.530	61.207
29	13.591	18.836	27.358	35.978	48.191	65.615
30	13.765	19.246	28.302	37.601	50.953	70.272

Table 15-4

Values of P/X (d, r, n) for Discount Rate of 8 Percent

Years	Annual Rate of Increase					
	0	3	6	8	10	12
10	6.710	7.550	8.525	9.259	10.070	10,965
11	7.139	8.127	9.293	10.185	11.183	12.297
12	7.536	8.676	10.046	11.111	12.316	13.673
13	7.904	9.200	10.786	12.037	13.470	15.111
14	8.244	9.700	11.513	12.963	14.645	16.597
15	8.559	10.177	12.225	13.889	15.842	18.137
16	8.851	10.632	12.926	14.815	17.061	19.735
17	9.122	11.066	13.611	15.741	18.303	21.392
18	9.372	11.479	14.285	16.667	19.568	23.110
19	9.604	11.874	14.947	17.593	20.856	24.892
20	9.818	12.250	15.596	18.519	22.169	26.740
21	10.017	12.609	16.233	19.444	23.505	28.656
22	10.201	12.951	16.858	20.370	24.866	30.643
23	10.371	13.277	17.472	21.296	26.253	32.704
24	10.529	13.589	18.074	22.222	27.665	34.841
25	10.675	13.885	18.666	23.148	29.103	37.058
26	10.810	14.169	19.246	24.074	30.568	39.356
27	10.935	14.438	19.815	25.000	32.060	41.740
28	11.051	14.696	20.374	35.926	33.580	44.212
29	11.158	14.942	20.923	26.852	35.127	46.775
30	11.258	15.176	21.461	27.778	36.704	49.433

Table 15-5

Values of P/X (d, r, n) for Discount Rate of 10 Percent

Years	Annual Rate of Increase					
	0	3	6	8	10	12
10	6.145	6.884	7.739	8.382	9.091	9.872
11	6.495	7.355	8.366	9.139	10.000	10.961
12	6.814	7.796	8.971	9.882	10.909	12.069
13	7.103	8.209	9.554	10.611	11.818	13.197
14	7.367	8.596	10.116	11.377	12.727	14.346
15	7.606	8.958	10.657	12.030	13.636	15.516
16	7.824	9.297	11.179	12.721	14.545	16.708
17	8.022	9.614	11.681	13.399	15.455	17.920
18	8.201	9.911	12.166	14.064	16.365	19.155
19	8.365	10.190	12.632	14.717	17.273	20.413
20	8.514	10.450	13.082	15.359	18.182	21.693
21	8.649	10.695	13.515	15.989	19.091	22.997
22	8.772	10.923	13.933	16.607	20.000	24.324
23	8.883	11.137	14.335	17.214	20.909	25.675
24	8.985	11.337	14.723	17.810	21.818	27.051
25	9.077	11.525	15.097	18.396	22.727	28.452
26	9.161	11.701	15.457	18.970	23.636	29.878
27	9.237	11.865	15.804	19.534	24.545	31.331
28	9.307	12.019	16.138	20.088	25.455	32.809
29	9.370	12.613	16.461	20.632	26.364	34.315
30	9.427	12.299	16.771	21.166	27.273	35.848

Table 15-6

Values of P/X (d, r, n) for Discount Rate of 12 Percent

Years	Annual Rate of Increase					
	0	3	6	8	10	12
10	5.650	6.303	7.057	7.822	8.244	8.929
11	5.938	6.690	7.571	8.243	8.990	9.821
12	6.194	7.045	8.059	8.841	9.722	10.714
13	6.424	7.372	8.520	9.418	10.441	11.607
14	6.628	7.672	8.956	9.975	11.148	12.500
15	6.811	7.949	9.369	10.511	11.842	13.393
16	6.974	8.203	9.760	11.029	12.523	14.286
17	7.120	8.436	10.130	11.528	13.192	15.179
18	7.250	8.651	10.480	12.009	13.850	16.071
19	7.366	8.849	10.812	12.473	14.495	16.964
20	7.469	9.031	11.125	12.920	15.129	17.857
21	7.562	9.198	11.422	13.352	15.752	18.758
22	7.645	9.352	11.703	13.768	16.363	19.643
23	7.718	9.493	11.969	14.169	16.964	20.536
24	7.784	9.623	12.221	14.556	17.554	21.429
25	7.843	9.743	12.459	14.929	18.133	22.321
26	7.896	9.853	12.684	15.288	18.702	23.214
27	7.943	9.954	12.898	15.635	19.261	24.107
28	7.984	10.047	13.100	15.970	19.810	25.000
29	8.022	10.132	13.291	16.292	20.349	25.893
30	8.055	10.211	13.472	16.603	20.879	26.786

The economic factor E_1 is slightly more involved and is expressed as:

$$E_1 = \alpha + [(1 - t)p + h]P/X\,(d,g,n) +$$

$$(1 - \alpha)\left[(1 - t)\,\frac{P/X\,(d,0,m)}{P/X\,(i,0,m)} + (t)\,\frac{P/X\,(d,i,m)}{P/X\,(0,i,m)}\right] \qquad [15\text{-}10]$$

where α is the downpayment rate in the terms of the loan and fixed mortgage payment is assumed,

t is the effective income tax rate of the owner,

p is the property tax rate based on initial capital cost (first year market value),

h is the insurance premium rate,

g is the inflation rate for general cost of goods and services (general inflation rate),

i is the interest rate of the loan,

m is the term (years) of the loan

Values of P/X (a,b,c) may be determined from Tables 15-1 through 15-6 by referring to the appropriate values in the tables as indicated by the terms in the parentheses following P/X. For example, P/X (d,0,m) may be determined by consulting the appropriate discount rate d, rate of annual increase 0, and years m.

EXAMPLE 15-1

Determine the economic factors E_o, E_m, and E_f if the annual rate of increase for operating cost, r_o, is 10 percent, annual rate of increase for maintenance, r_m, is 6 percent, annual rate of increase for fuel, r_f. is 12 percent, and the discount rate is 8 percent for a life of 20 years.

Solution:

E_o = P/X (8,10,20) = 22.169 (from Table 15-4)

E_m = P/X (3,6,20) = 15.596 (from Table 15-4)

E_f = P/X (8,12,20) = 26.740 (from Table 15-4)

EXAMPLE 15-2

Determine the economic factor E_1 if the terms of the loan are m = 25 years, i = 10 percent, and α = 20 percent downpayment. The property tax rate, p, is 3 percent and insurance rate, h, is 0.3 percent of market value, general inflation rate, g,g is 6 percent, and the effective income tax rate is 35 percent. The market discount rate, d, is 8 percent.

Solution:

For Equation [15-10], find appropriate P/X values from the tables.

P/X (d,g,n) = P/X (8,6,20) = 15.596

P/X (d,0,m) = P/X (8,0,25) = 10.675

P/X (i,0,m) = P/X (10,0,25) = 9.077

P/X (d,i,m) = P/X (8,10,35) = 29,103

P/X (0,i,m) = P/X (0,10,25) = 98,347

$\alpha = 0.20$

$t = 0.35$

$p = 0.03$

$h = 0.003$

Thus,

$$E_1 = 0.20 + [(1 - .35)(0.03) + 0.003](15.596) + (1 - 0.2)[(1 - .35)\frac{10.675}{9.077} + (0.35)\frac{29.103}{98.347}]$$

$$E_1 = 1.245 \qquad \text{(ans)}$$

EXAMPLE 15-3

Determine the present values of life-cycle costs of a solar system, a non-solar system and the savings with a solar system, given the following information:

$A = 500\ ft^2$	$r_m = 6\%$
$C_a = 26\ \$/ft^2$	$r_f = 12\%$
$C_o = 87\ \$/yr$	$m = 25$ years
$C_{oc} = 20\ \$/yr$	$i = 10\%$
$C_m = 100\ \$/yr$	$\alpha = 20\%$ down
$C_{mc} = 10\ \$/yr$	$p = 3\%$ of market value
$F = 0.68$	$h = 0.3\%$ of market value
$c_f = 10.25\ \$/MMBtu$	$g = 6\%$
$L = 130\ MMBtu$	$t = 35\%$
$r_o = 10\%$	$d = 8\%$

Solution:

The equation to apply for the solar system is Equation [15-13]. From Example 15-1, $E_o = 22.169$, $E_m = 15.596$, $E_f = 26.740$. From Example 15-2, $E_1 = 1.245$

Therefore,

$$C_T = (500)(26)(1.245) + (87)(22.169) + (100)(15.596) + (1 - .68)(130)(10.25)(26.740)$$

C_T = \$31,075 present value over 20 years of life

The equation to apply to the non-solar system is Equation [15-4].

$$C_{TC} = (20)(22.169) + (20)(15.596) + (130)(10.25)(26.740)$$

C_{TC} = \$36,230 present value over 20 years of life

The cost of the non-solar is clearly larger than the cost of the solar system. The difference, or savings realizable with the solar system, is:

$$\text{Present value of savings} = C_{TC} - C_T = 36{,}230 - 31{,}075 = \$5155$$

While in Example 15-3 the present values of the total costs for systems and life time savings are determinable, the calculations are restricted to fixed annual increases, fixed discount rates, fixed property tax and insurance rates, and fixed income tax rates for the owner. These rates are, of course, uncertain in future years and highly variable. If variable rates are to be applied, a detailed year by year analysis of cash flow and present worth discounting must be carried out, using the basic form of Equations [15-1] and [15-2].

Annual cash flows are calculated for a system and the annual cost may be discounted to present value. The cost in a future year may be discounted to present worth by multiplying the cost by the present worth factor, P, in:

$$P = \frac{1}{(1+d)^q} \qquad [15\text{-}11]$$

where

q is any year in the analysis period from 1 to n

d is the market discount rate

Values of P for practical ranges of d and q are tabulated in Table 15-7.

ENERGY COSTS

The conversion of unit costs of energy to dollars per million Btu ($/MMBtu) with various furnace efficiencies are shown on Figure 15-1 for

Table 15-7
Present Worth Factors (P)
(use for Worksheet LCA-4)

	DISCOUNT RATE										
Year of Analysis	6	7	8	9	10	11	12	13	14	15	16
1	.943	.935	.926	.917	.909	.901	.893	.885	.877	.870	.862
2	.890	.873	.857	.842	.826	.812	.797	.783	.769	.756	.743
3	.840	.816	.794	.772	.751	.731	.712	.693	.675	.658	.641
4	.792	.763	.735	.708	.683	.659	.636	.613	.592	.572	.552
5	.747	.713	.681	.650	.621	.593	.567	.543	.519	.497	.476
6	.705	.666	.630	.596	.564	.535	.507	.480	.456	.432	.410
7	.665	.623	.583	.547	.513	.482	.452	.425	.400	.376	.354
8	.627	.582	.540	.502	.467	.434	.404	.376	.351	.327	.305
9	.592	.544	.500	.460	.424	.391	.361	.333	.308	.284	.263
10	.558	.508	.463	.422	.386	.352	.322	.295	.270	.247	.227
11	.527	.475	.429	.388	.350	.317	.287	.261	.237	.215	.195
12	.497	.444	.397	.356	.319	.286	.257	.231	.208	.187	.168
13	.469	.415	.368	.326	.290	.258	.229	.204	.182	.163	.145
14	.442	.388	.340	.299	.263	.232	.205	.181	.160	.141	.125
15	.417	.362	.315	.275	.239	.209	.183	.160	.140	.123	.108
16	.394	.339	.292	.252	.218	.188	.163	.141	.123	.107	.093
17	.371	.317	.270	.231	.198	.170	.146	.125	.108	.093	.080
18	.350	.296	.250	.212	.180	.153	.130	.111	.095	.081	.069
19	.331	.277	.232	.194	.164	.138	.116	.098	.083	.070	.060
20	.312	.258	.215	.178	.149	.124	.104	.087	.073	.061	.051
21	.294	.242	.199	.164	.135	.112	.093	.077	.064	.053	.044
22	.278	.226	.184	.150	.123	.101	.083	.068	.056	.046	.038
23	.262	.211	.170	.138	.112	.091	.074	.060	.049	.040	.033
24	.247	.197	.158	.126	.102	.082	.066	.053	.043	.035	.028
25	.233	.184	.146	.116	.092	.074	.059	.047	.038	.030	.024

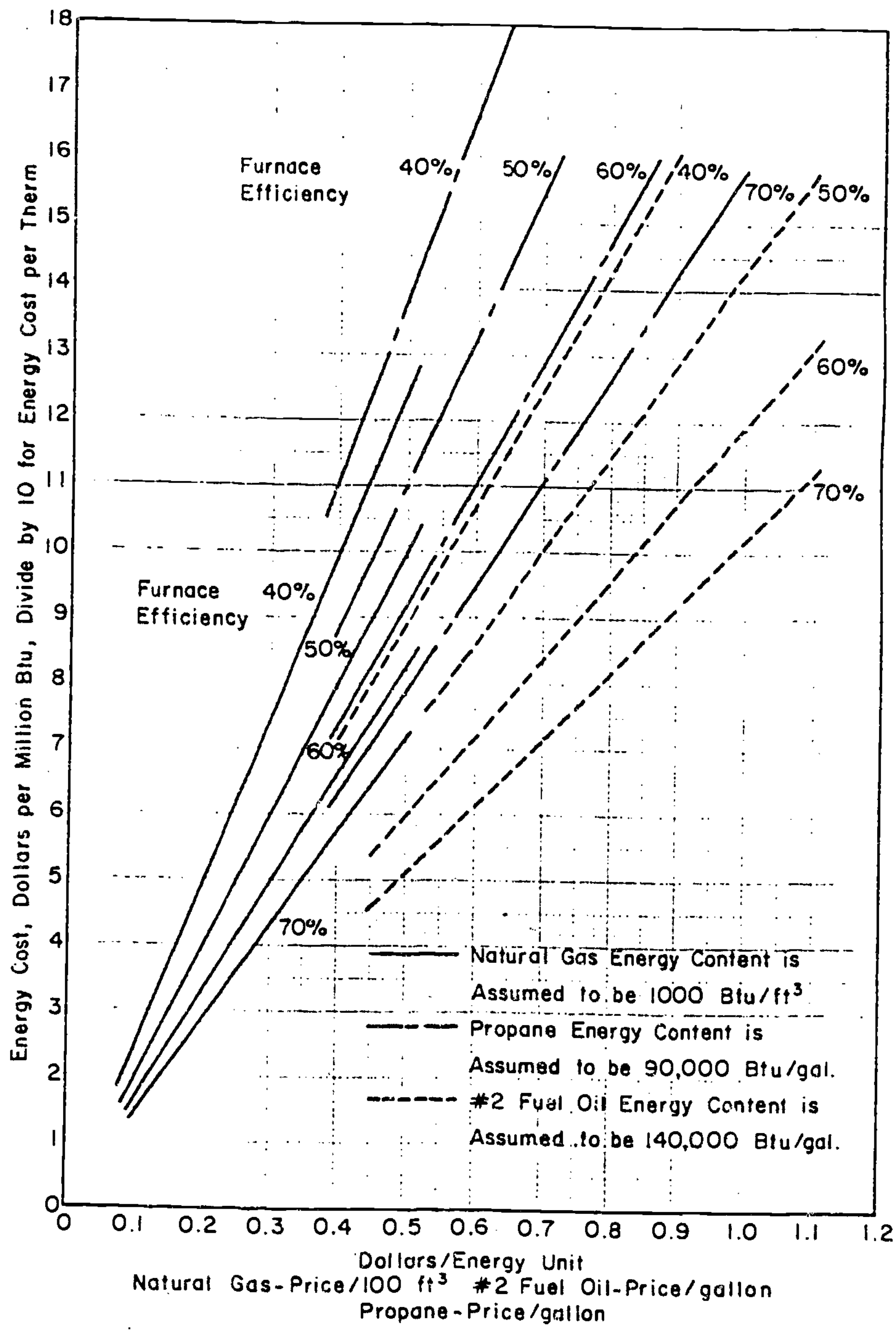

Figure 15-1. Energy Cost per Million Btu for Natural Gas, Propane and No. 2 Fuel Oil.

natural gas, propane, and No. 2 fuel oil. The conversion of electric energy costs to dollars per million Btu for resistance heating and heat pumps with various coefficients of performance are shown on Figure 15-2. To determine the cost per million Btu of heat generated from furnaces, electric resistance heaters, or heat pumps, follow the unit cost of energy, found on the horizontal axis of the graphs, vertically to the appropriate line on the graph and read the cost in dollars along the vertical exis. For example, if No. 2 fuel oil costs fifty cents per gallon, and the furnace efficiency is 60 percent, the energy cost is \$6.00/MMBtu or 60 cents per therm (¢/therm). If the furnace is more efficient, say 70 percent, the energy cost is \$5.10/MMBtu or 51 ¢/therm. Similarly, if electricity costs three cents per kilowatt-hour (C/kWh), and resistance heating is used, the energy cost is \$8.80/MMBtu. If a heat pump is used, and the COP of the heat pump is 2, the energy cost is \$4.40/MMBtu.

The cost of energy will increase in future years and an estimate of the rate of increase is subject not only to inflation rates of goods and services, but also to economic and political decisions of the federal government and the governments of other nations. On expects, however, the rate of fuel cost increases to be different from "normal" inflation rates and higher by a few percent, at least for the immediate future.

INFLATION RATES

The increases in costs per unit of energy, several years in the future in terms of cents per gallon, cents per kilowatt-hour, cents per hundred cubic feet of natural gas, or dollars per therm, can be estimated on the basis of annual percentage increases over current costs.

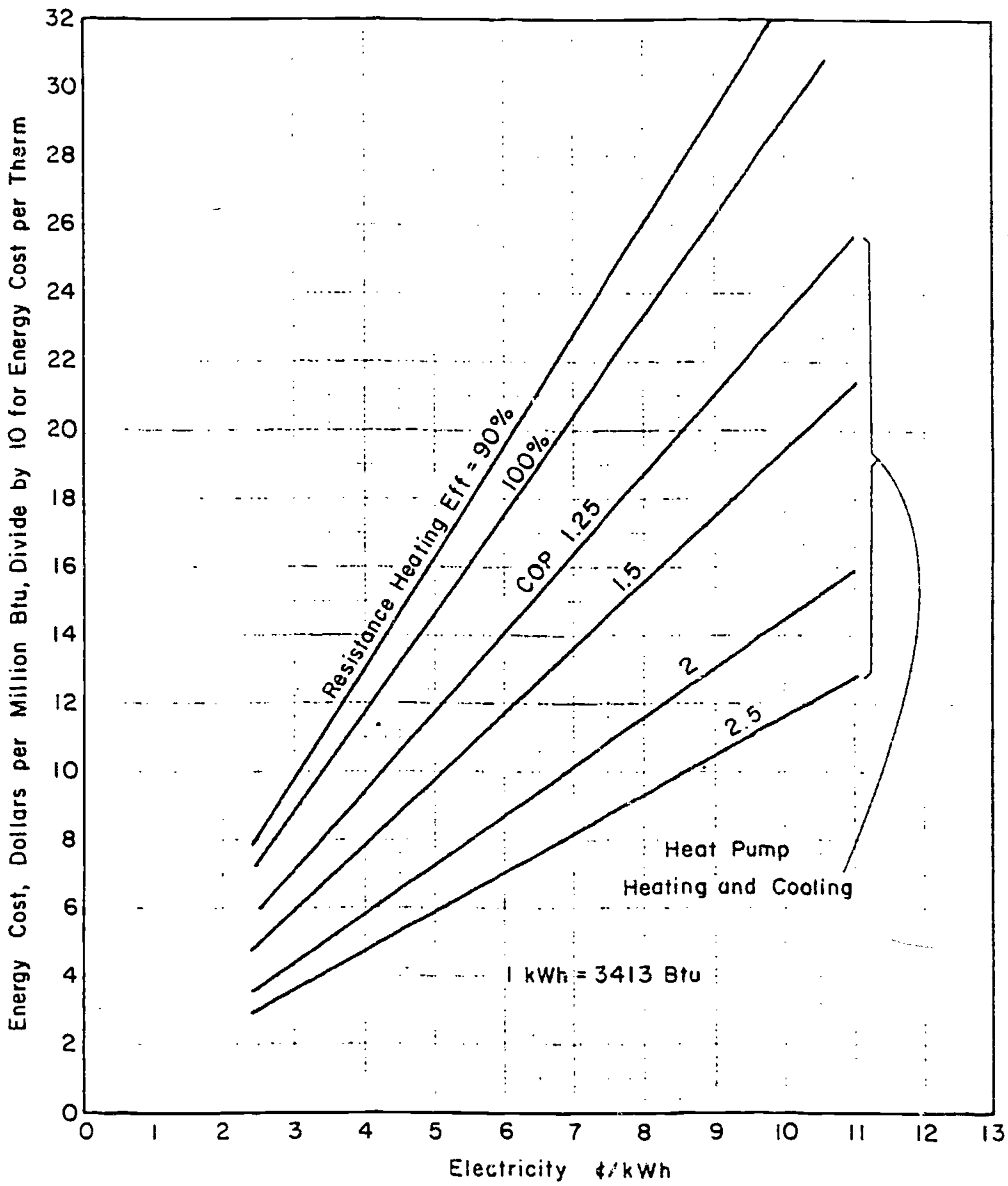

Figure 15-2. Energy Cost per Million Btu for Electricity

The multiplying factors for current energy costs to determine future costs is shown on Figure 15-3. The horizontal axis is the years beyond the current year. The vertical axis gives the multiplying factor over current costs, and is simply the interest compounded annually, $(1+i)^n$.

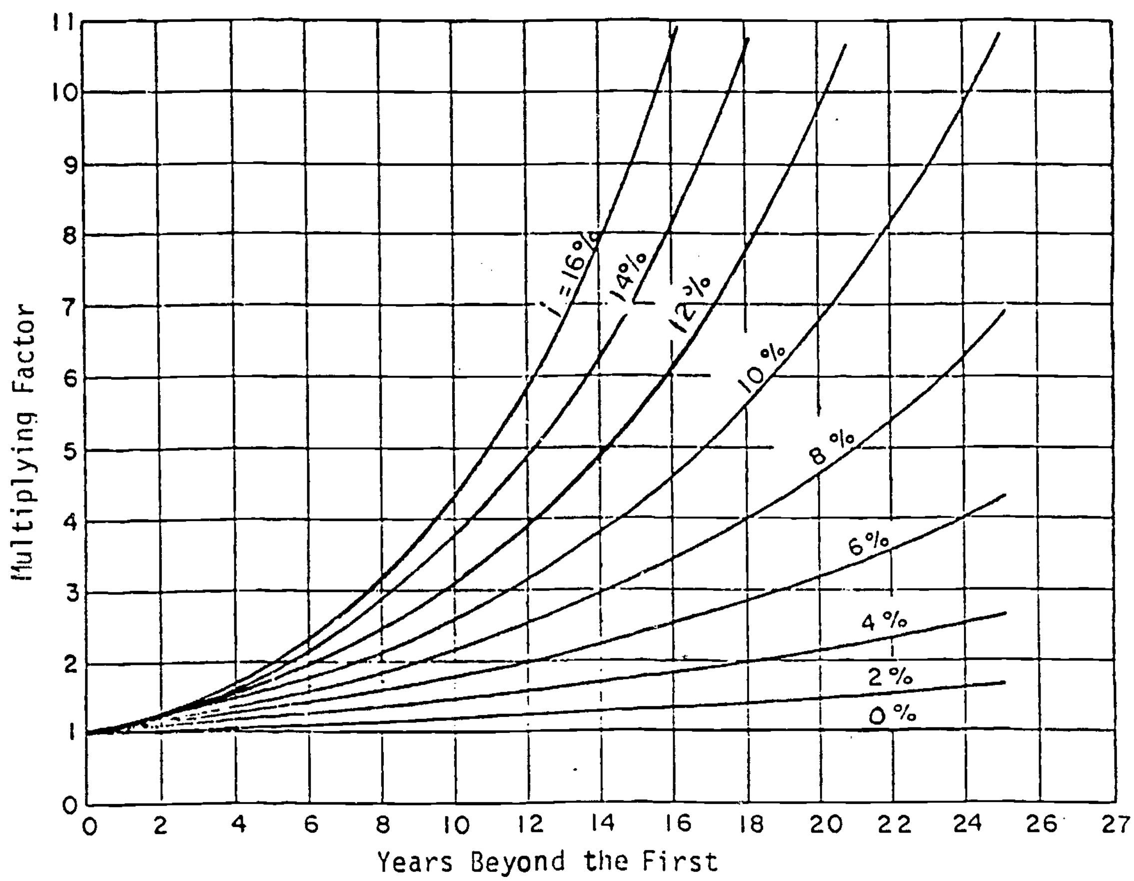

Figure 15-3. Inflation Factors

For example, if the current cost of electricity is expected to increase at a rate of 6 percent each year for the next 12 years, at the end of 12 years the electricity cost will double. If 3¢/kWh is the current cost and heating cost is $8.80/MMBtu, at the end of 12 years the electricity will cost 6¢/kWh and $17.80/MMBtu.

INSTALLED COSTS

There is much speculation about the installed costs of complete solar systems and there is little information available to substantiate published information on costs. System costs based on research projects and demonstration projects funded by the federal government are misleading because the total costs of such projects include considerable engineering design costs, research staff costs, in some instances instrument costs for monitoring the performance of experimental systems, and often development costs of several alternative components in the systems are included. The costs reported in popular magazines and newspaper accounts are likewise misleading because often systems which are designed and assembled by the owner on a do-it-yourself basis are cited and costs for the owner's time is seldom included in the cost quotations.

On the basis of a few commercial solar installations made, where no governmental subsidy has been involved, the installed cost of practical solar space and hot water heating systems of the types discussed in this course range from 19 to about 30 dollars per square foot. The lower cost is appropriate for simply hydronic and air systems, ranging in size from 500 to 1000 square feet of collectors, where some economy of scale is realized over small systems and where experienced installers and timely scheduling is arranged with the building construction. The higher costs are appropriate for smaller systems and difficult installations.

The costs for collectors currently (1977) range from 7 to about 15 dollars per square foot, F.O.B. the job site, with more efficient collectors being generally more expensive. Storage will add one to two dollars per square foot of collector to the system costs, and appurtenances, from 5 to 8 dollars per square foot. Including the cost for experienced labor for installation, overhead, and profit of 6 to 8 dollars per square foot, the installed system costs range from 19 to 33 dollars per square foot of collector, with an average cost of about 25 dollars per square foot.

MORTGAGE PAYMENTS

The largest portion of the annual cost of a solar system is the repayment of the loan obtained to install the system. The loan may be based on the total building costs or separately on the solar system alone. In either event, a downpayment ranging from 10 to 20 percent is required to secure the loan. The annual mortgage payments can be calculated from the mortgage interest rate and term of the loan using the curves of Figure 15-4.

To illustrate the use of Figure 15-4, suppose that a solar system with 500 square feet of collectors cost \$12,500 (determined by 500 $ft^2 \times \$25/ft^2$). A 20-year loan is obtained to purchase and install the system with interest at 9 percent, which requires a 20 percent downpayment. The annual mortgage payment on the loan is calculated as:

$$\text{Annual Mortgage Payment} = (\text{System cost} - \text{downpayment}) \times \underset{\text{(from Figure 15-4)}}{(\text{Annual repayment factor})}$$

or

$$\$1100 = (12,500 - 2500) \times (0.11)$$

PROPERTY TAX, INSURANCE, AND CREDIT ON INCOME TAXES

The annual cost of a solar system includes all the items contributing to the cash flow to operate a solar heating system. The costs include the mortgage payment and fuel costs, operating and maintenance costs, property

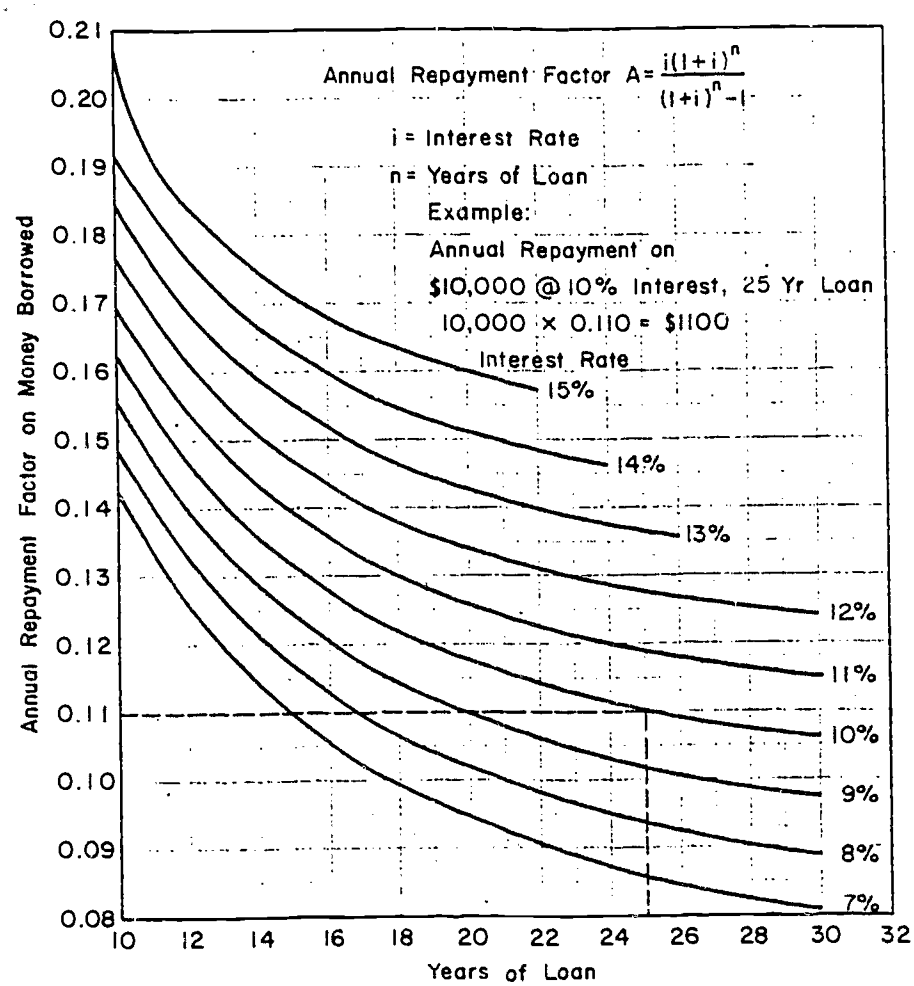

Figure 15-4. Repayment on Loan

tax, insurance on the solar system, and savings on federal and state income taxes for property tax and interest paid on the loan. A major item is the Federal Tax Credit, which allows a maximum credit of $2200 to be subtracted from the owner's federal income tax liability. The credit allowance is 30 percent of the first $2000 plus 20 percent of the next $8000 of the cost of the installed system. In some states there are additional credits provided to state income taxes for owners of solar systems.

Property taxes are based on a fraction of the assessed value of the solar system. The method of assessment, and the tax rate, varies from state to state and sometimes from county to county within the state. The office of the county treasurer can provide detailed information on method of assessed valuation on property and the tax rate. Usually, the assessed value is a fraction of the market value of the property and the tax rate is applied to the assessed value. The property tax rate varies widely, from zero in some states to over ten percent in others. The amount of property tax on the solar system can be calculated as follows:

$$\text{Property tax} = (\text{System cost}) \times (\text{Fraction of assessed value}) \times (\text{tax rate})$$

Insurance rates on houses with a solar system, at present, are the same as for houses without solar systems. The basic insurance rate depends upon the type of house construction and location of the building within or outside a city or town. The insurance rate for a comprehensive homeowners policy differs from that for a straight fire insurance policy and the insurance rates for earthquake and flood damage (which is federally subsidized) are the only special insurances available for owners of buildings. The information on various insurance rates are available from local insurance agents. However, very few insurance companies have established insurance rates for solar systems. Damage to the contents of a building resulting from leaks in piping or storage tanks or damage to the solar system resulting from flooding by natural causes is based on comprehensive or flood insurance rates. Although there are many factors to be considered, the annual premium on insurance for houses with solar systems is less than one percent of the value of the house and contents, and ranges from 0.3 to about 0.6 percent.

The "savings" on state and federal income taxes for property tax and interest paid on the mortgage can be substantial, depending upon the "tax bracket" of the homeowner. The amount of interest paid annually on the mortgage decreases with the number of years remaining on the mortgage. The portion of annual mortgage which is paid as interest can be determined from Tables 5-8 through 5-12. The use of tables is illustrated in the following example.

Let us assume that a loan of $10,000 has been secured at a term of 20 years and 9 percent interest. The annual mortgage payment was computed in the previous section to be $1100. From Table 5-10 it is noted that 0.822 of the mortgage payment or $900, is for interest in the first year. In the eleventh year, the interest amounts to (0.578) x ($1100) or $636. The income tax savings on a federal or state return for interest and taxes would be:

$$\left(\begin{matrix}\text{Income}\\ \text{tax credit}\end{matrix}\right) = \left(\begin{matrix}\text{Interest and}\\ \text{taxes}\end{matrix}\right) \times \left(\begin{matrix}\text{Tax rate based}\\ \text{on net income}\end{matrix}\right)$$

The federal income tax return provides credit for state income taxes paid and many states give credit for federal income taxes. Thus the full credit for tax savings resulting from payment of interest is not simply the sum of state and federal tax savings. The net effective rate for states giving credit is:

Table 15-8. Fraction of Mortgage Payment (A) Which is Interest
$I/A = 1-(1+i)^{j-m-1}$ Mortgage Term (m) = 10 years

YEAR (j)	INTEREST RATE									
	6	7	8	9	10	11	12	13	14	15
1	.442	.492	.537	.578	.614	.648	.678	.705	.730	.753
2	.408	.456	.500	.540	.576	.609	.639	.667	.692	.716
3	.373	.418	.460	.498	.533	.566	.596	.624	.649	.673
4	.335	.377	.417	.453	.487	.518	.548	.575	.600	.624
5	.295	.334	.370	.404	.436	.465	.493	.520	.544	.568
6	.253	.287	.319	.350	.379	.407	.433	.457	.481	.503
7	.208	.237	.265	.292	.317	.341	.364	.387	.408	.428
8	.160	.184	.206	.228	.249	.269	.288	.307	.325	.342
9	.110	.127	.143	.158	.174	.188	.203	.217	.231	.244
10	.057	.065	.074	.083	.091	.099	.107	.115	.123	.130

Table 15-9. Fraction of Mortgage Payment (A) Which is Interest
$I/A = 1-(1+i)^{j-m-1}$ Mortgage Term (m) = 15 years

YEAR (j)	INTEREST RATE									
	6	7	8	9	10	11	12	13	14	15
1	.583	.638	.685	.725	.761	.791	.817	.840	.860	.877
2	.588	.612	.660	.701	.737	.768	.795	.819	.840	.859
3	.531	.585	.632	.674	.710	.742	.771	.796	.818	.837
4	.503	.556	.603	.644	.681	.714	.743	.769	.792	.813
5	.473	.525	.571	.612	.650	.683	.713	.739	.763	.785
6	.442	.492	.537	.578	.614	.648	.678	.705	.730	.753
7	.408	.456	.500	.540	.576	.609	.639	.667	.692	.716
8	.373	.418	.460	.498	.533	.566	.596	.624	.649	.673
9	.335	.377	.417	.453	.487	.518	.548	.575	.600	.624
10	.295	.334	.370	.404	.436	.465	.493	.520	.344	.568
11	.253	.287	.319	.350	.379	.407	.433	.457	.481	.503
12	.208	.237	.265	.292	.317	.341	.364	.387	.408	.428
13	.160	.184	.206	.228	.249	.269	.288	.307	.325	.342
14	.110	.127	.143	.158	.174	.188	.203	.217	.231	.244
15	.057	.065	.074	.083	.091	.099	.107	.115	.123	.130

Table 15-10. Fraction of Mortgage Payment (A) Which is Interest
$I/A = 1-(1+i)^{j-m-1}$ Mortgage Term (m) = 20 years

YEAR (j)	INTEREST RATE									
	6	7	8	9	10	11	12	13	14	15
1	.688	.742	.785	.822	.851	.876	.896	.913	.927	.939
2	.669	.723	.768	.806	.836	.862	.884	.902	.917	.930
3	.650	.704	.750	.788	.820	.847	.870	.889	.905	.919
4	.629	.683	.730	.769	.802	.830	.854	.875	.892	.907
5	.606	.661	.708	.748	.782	.812	.837	.859	.877	.893
6	.583	.638	.685	.725	.761	.791	.817	.840	.860	.877
7	.558	.612	.660	.701	.737	.768	.795	.819	.840	.859
8	.531	.585	.632	.674	.710	.742	.771	.796	.818	.837
9	.503	.556	.603	.644	.681	.714	.743	.769	.792	.813
10	.473	.525	.571	.612	.650	.683	.713	.739	.763	.785
11	.442	.492	.537	.578	.614	.648	.678	.705	.730	.753
12	.408	.456	.500	.540	.576	.609	.639	.667	.692	.716
13	.373	.418	.460	.498	.533	.566	.596	.624	.649	.673
14	.335	.377	.417	.453	.487	.518	.548	.575	.600	.624
15	.295	.334	.370	.404	.436	.465	.493	.520	.544	.568
16	.253	.287	.319	.350	.379	.407	.433	.457	.481	.503
17	.208	.237	.265	.292	.317	.341	.364	.387	.408	.428
18	.160	.184	.206	.228	.249	.269	.288	.307	.325	.342
19	.110	.127	.143	.158	.174	.188	.203	.217	.231	.244
20	.057	.065	.074	.083	.091	.099	.107	.115	.123	.130

100

Table 15-11. Fraction of Mortgage Payment (A) Which is Interest
$I/A = 1-(1+i)^{j-m-1}$ Mortgage Term (m) = 25 years

YEAR (j)	INTEREST RATE									
	6	7	8	9	10	11	12	13	14	15
1	.767	.816	.854	.884	.908	.926	.941	.953	.962	.970
2	.753	.803	.842	.874	.898	.918	.934	.947	.957	.965
3	.738	.789	.830	.862	.888	.909	.926	.940	.951	.960
4	.722	.774	.816	.850	.877	.899	.917	.932	.944	.954
5	.706	.758	.810	.836	.865	.888	.907	.923	.936	.947
6	.688	.742	.785	.822	.851	.876	.896	.913	.927	.939
7	.669	.723	.768	.806	.836	.862	.884	.902	.917	.930
8	.650	.704	.750	.788	.820	.847	.870	.889	.905	.919
9	.629	.683	.730	.769	.802	.830	.854	.875	.892	.907
10	.606	.661	.708	.748	.782	.812	.837	.859	.877	.893
11	.583	.638	.685	.725	.761	.791	.817	.840	.860	.877
12	.558	.612	.660	.701	.737	.768	.795	.819	.840	.859
13	.531	.585	.632	.674	.710	.742	.771	.796	.818	.837
14	.503	.556	.603	.644	.681	.714	.743	.769	.792	.813
15	.473	.525	.571	.612	.650	.683	.713	.739	.763	.785
16	.442	.492	.537	.578	.614	.648	.678	.705	.730	.753
17	.408	.456	.500	.540	.576	.609	.639	.667	.692	.716
18	.373	.418	.460	.498	.533	.566	.596	.624	.649	.673
19	.335	.377	.417	.453	.487	.518	.548	.575	.600	.624
20	.295	.334	.370	.404	.436	.465	.493	.520	.544	.568
21	.253	.287	.319	.350	.379	.407	.433	.457	.481	.503
22	.208	.237	.265	.292	.317	.341	.364	.387	.408	.428
23	.160	.184	.206	.228	.249	.269	.288	.307	.325	.342
24	.110	.127	.143	.158	.174	.188	.203	.217	.231	.244
25	.057	.065	.074	.083	.091	.099	.107	.115	.123	.130

Table 15-12.- Fraction of Mortgage Payment (A) Which is Interest

$I/A = 1-(1+i)^{j-m-1}$ Mortgage Term (m) = 30 years

YEAR (j)	INTEREST RATE									
	6	7	8	9	10	11	12	13	14	15
1	.826	.869	.901	.925	.943	.956	.967	.974	.980	.985
2	.815	.859	.893	.918	.937	.952	.963	.971	.978	.983
3	.804	.850	.884	.910	.931	.946	.958	.967	.974	.980
4	.793	.839	.875	.902	.924	.940	.953	.963	.971	.977
5	.780	.828	.865	.894	.916	.934	.947	.958	.967	.974
6	.767	.816	.854	.884	.908	.926	.941	.953	.962	.970
7	.753	.803	.842	.874	.898	.918	.934	.947	.957	.965
8	.738	.789	.830	.862	.888	.909	.926	.940	.951	.960
9	.722	.774	.816	.850	.877	.899	.917	.932	.944	.954
10	.706	.758	.801	.836	.865	.888	.907	.923	.936	.947
11	.688	.742	.785	.822	.851	.876	.896	.913	.927	.939
12	.669	.723	.768	.806	.836	.862	.884	.902	.917	.930
13	.650	.704	.750	.788	.820	.847	.870	.889	.905	.919
14	.629	.683	.730	.769	.802	.830	.854	.875	.892	.907
15	.606	.661	.708	.748	.782	.812	.837	.859	.877	.893
16	.583	.638	.685	.725	.761	.791	.817	.840	.860	.877
17	.558	.612	.660	.701	.737	.768	.795	.819	.840	.859
18	.531	.585	.632	.674	.710	.742	.771	.796	.818	.837
19	.503	.556	.603	.644	.681	.714	.743	.769	.792	.813
20	.473	.525	.571	.612	.650	.683	.713	.739	.763	.785
21	.442	.492	.537	.578	.614	.648	.678	.705	.730	.753
22	.408	.456	.500	.540	.576	.609	.639	.667	.692	.716
23	.373	.418	.460	.498	.533	.566	.596	.624	.649	.673
24	.335	.377	.417	.453	.487	.518	.548	.575	.600	.624
25	.295	.334	.370	.404	.436	.465	.493	.520	.544	.568
26	.253	.287	.319	.350	.379	.407	.433	.457	.481	.503
27	.208	.237	.265	.292	.317	.341	.364	.387	.408	.428
28	.160	.184	.206	.228	.249	.269	.288	.307	.325	.342
29	.110	.127	.143	.158	.174	.188	.203	.217	.231	.244
30	.057	.065	.074	.083	.091	.099	.107	.115	.123	.130

$$\text{Net (Effective) Rate} = \binom{\text{Federal}}{\text{tax rate}} + \binom{\text{State}}{\text{tax rate}} - 2 \binom{\text{Federal}}{\text{tax rate}} \times \binom{\text{State}}{\text{tax rate}}$$

For states which do not give credit, the net effective rate is:

$$\text{Net (Effective) Rate} = \binom{\text{Federal}}{\text{tax rate}} + \binom{\text{State}}{\text{tax rate}} - 1 \binom{\text{Federal}}{\text{tax rate}} \times \binom{\text{State}}{\text{tax rate}}$$

If the income tax rate on a federal tax return is 25 percent and on a state tax return is 10 percent, the net effective rate is (0.25 + 0.10 - 2 x 0.25 x 0.10) 0.30, or 30 percent. The net annual income tax savings realized on the federal and state taxes for interest alone is (0.30)x($900), or $270 in the first year and (0.30)x($636), or $191 in the eleventh year.

OPERATING COSTS

The cost of operating a solar heating system, including the cost for operating the auxiliary unit in the system, is the cost of electric energy required to operate the pumps, central heat distribution fan, valves, and controller in a hydronic system, and the blowers, motorized dampers, and controller in an air system. The amount of energy used to collect, store, and distribute solar energy varies from system to system in the range from 5 to 10 percent of the total solar energy collected. The lower values in the range apply to low-head systems with small pressure drops, and air systems with single blowers with small pressure drops. The higher values in the range apply to high-head systems with large pressure drops, small systems with large pumps, and air systems with two blowers.

The operating cost for a non-solar system is much less than for a solar system. Although the blower size for distributing air to the rooms is the same, the power requirement is less for a non-solar system because the pressure drop in the system is lower. As an approximation, the energy required to operate a non-solar system is two to three percent of the total annual heating load.

MAINTENANCE COSTS

The maintenance costs for solar systems is unknown; there is insufficient long-term experience with various systems to indicate an appropriate maintenance cost. While there is one air system that has been operated continuously for 19 years, on which the maintenance cost was zero, it can be expected that all solar systems will require some amount of maintenance during the life of the system. For the purpose of economic analysis, maintenance costs can be included each year for a nominal amount, say one hundred dollars, escalated annually at a selected inflation rate.

ECONOMIC ANALYSIS WORKSHEETS

There are included in this section a "short" method and a "long" method of calculating the cash flow and present worth of cash flow over the life of a system. The short method provides a calculation of total system cost over the life of the system or, if desired, the present worth of system cost. The long method provides a year-by-year analysis of system cost and annual rates of increase can be changed for any item for any year. Life-cycle cost analyses enable one to determine if a given solar system is economical, and by extending the analyses to different collector areas for a given installation, it is possible to determine an economically optimum size based upon the minimum cost of the solar-auxiliary system or the maximum savings realizable with the solar-auxiliary system over a non-solar heating system. The procedures are outlined on worksheets and the computation steps are fully explained (on the worksheets).

Sheets 1 and 2 of Worksheet LCA-1 are data sheets common to both the short and long methods. The short method of life-cycle analysis is computed by using Worksheet LCA-2. The total cash flow, present value of cash flow, or present value of total savings can be determined on the short form. Worksheet LCA-3 is used to determine the annual cost of the solar system and the cumulative cost over the life of the system. The present values of the annual cost and annual savings, with a solar system compared to a non-solar system, are determined on Worksheet LCA-4, and total costs are the sums of the appropriate columns.

WORKSHEET LCA-1

Worksheet LCA-1 is a data sheet to facilitate life-cycle cost analysis. Technical, economic, and cost data are listed, and cross-references to the design worksheets are provided for specific items where necessary. All items on the worksheet are self-explanatory.

WORKSHEET LCA-2

Worksheet LCA-2 details the "short" method for life-cycle cost of a solar system. The economic factors, E values, are determined from Tables 15-1 through 15-6 using the data in Worksheet LCA-1.

DATA SHEET FOR ECONOMIC ANALYSIS

Project ______________________

Building Data (see Worksheet B)

1. Annual space heating load ____________ mBtu/yr
2. Annual DHW heating load ____________ mBtu/yr
3. Total H and DHW load (add lines 1 and 2) ____________ mBtu/yr

Solar System Data (see Worksheet G)

4. Collector area ____________ ft^2
5. Fraction of annual heating load supplied from solar ____________ decimal
6. Total annual solar heat collected (multiply line 5 and line 3) ____________ mBtu/yr
7. Fraction of solar heat needed for electric power to operate the heating system (estimate, 0.06 to 0.10) ____________ decimal
8. Electric energy for operating (heat equivalent)(multiply line 6 by line 7) ____________ mBtu/yr
9. Auxiliary heating energy required (subtract line 6 from line 3) ____________ mBtu/yr

Non-Solar Heating System (Alternative)

10. Total annual heating load by conventional heating system (line 3) ____________ mBtu/yr
11. Electric energy required for operating non-solar system (heat equivalent) (estimate, 0.02 to 0.03 of line 10) ____________ mBtu/yr

Energy Prices

12. c_e, current energy cost for electricity (use Figure 15-2) ______ ¢/kWhr ____________ \$/mBtu
13. c_f, current cost of fuel for auxiliary heating (to solar system (use Figure 15-1 or 15-2) ____________ \$/mBtu
14. c_{fc}, current cost of fuel for non-solar system (use Figure 15-1 or 15-2) ____________ \$/mBtu

Financial Data

15. m, term of the loan for solar system ____________ yrs
16. α, downpayment ______ % ____________ decimal
17. i, interest rate on loan ______ % ____________ decimal
18. Annual mortgage rate for loan (from Figure 15-4 or standard mortgage loan tables) ____________ decimal

Economic Data

19. C_a, installed cost of solar system per unit area ____________ $\$/ft^2$
20. r_f, estimated auxiliary fuel inflation rate ____________ %
21. r_e, estimated electric energy inflation rate ____________ %
22. g, estimated general inflation rate ____________ %
23. p, property tax rate (based on market value) ____________ decimal
24. h, insurance premium rate ____________ decimal
25. Federal income tax rate for owner ____________ decimal
26. State income tax rate for owner ____________ decimal
27. t, effective income tax rate {i.e., (line 25) + (line 26) - [2 x (line 25) x (line 26)]} ____________ decimal
28. d, market discount rate ____________ decimal

Solar System Cost Items

29. Installed cost (multiply line 4 _______ by line 19 _______) ____________ $
30. Downpayment (multiply line 29 _______ by 16 _______) ____________ $
31. Federal tax credit for solar (30% of first $2000 plus 20% of next $8000) ____________ $
32. Amount of loan (line 29 minus line 30) ____________ $
33. Annual mortgage payment (multiply line 32 by line 18) ____________ $/yr
34. C_f, first year cost of auxiliary heating (multiply line 9 by line 13) ____________ $/yr
35. First year property tax (multiply line 29 by 23) ____________ $/yr
36. First year insurance premium (multiply line 29 by line 24) ____________ $/yr
37. C_o, first year cost of operating the solar system (multiply line 8 by line 12) ____________ $/yr
38. C_m, first year maintenance cost ____________ $/yr

Non-Solar System Cost Items

39. C_{fc}, first year cost of fuel for non-solar system (multiply line 10 by line 14) ____________ $/yr
40. C_{oc}, first year cost of operating non-solar system (multiply line 11 by line 12) ____________ $/yr

LIFE-CYCLE COST ANALYSIS

Total Cost for Solar System

41. n, total years of analysis ________ yrs

42. A, collector area ________ ft^2

43. L, annual heat load ________ MMBtu

44. F, fraction of annual heat provided by the solar system (line 5) ________ decimal

45. P/X (d,g,n) = P/X (___, ___, ___)
(line 28, line 22, line 41) ________

46. P/X (d,0,m) = P/X (___, 0, ___)
(line 28, 0, line 15) ________

47. P/X (i,0,m) = P/X (___, 0, ___)
(line 17, 0, line 15) ________

48. P/X (d,i,m) = P/X (___, ___, ___)
(line 28, line 17, line 15 ________

49. P/X (0,i,m) = P/X (0 , ___, ___)
(0, line 17, line 15) ________

50. $(t)[\frac{P/X\ (d,i,m)}{P/X\ (0,i,m)}] = (\frac{\text{line 27 x line 48}}{\text{line 49}})$ ________

51. $(1-t)[\frac{P/X\ (d,0,m)}{P/X\ (i,0,m}\ )] = \frac{\text{(1-line 27)(line 46)}}{\text{line 47}}$ ________

52. Add: line 50 + line 51 ________

53. 1 - α (1 - line 16) ________

54. Multiply: line 52 x line 53 ________

55. (1 - t)(p) + h
(1 - line 27)(line 23) + (line 24) ________

56. Multiply: line 55 x line 45 ________

57. E_1 = (line 16) + (line 56) + (line 54) ________

58. E_o = P/X (d,r_o,n) = P/X (___, ___, ___)
= P/X (line 28, line 21, line 41) ________

59. E_m = P/X (d,r_m,n) = P/X (___, ___, ___)
= P/X (line 28, line 22, line 41) ________

60. $E_f = P/X\ (d, r_r, n) = P/X\ (\_\_\_, \_\_\_. \_\_\_)$

$= P/X$ (line 28, line 20, line 41) __________

61. $(A)(C_a)(E_1)$ = (line 42)x(line 19)x(line 57) __________$

62. C_oE_o = (line 37)x(line 58) __________$

63. C_mE_m = (line 38)x(line 59) __________$

64. $(1-F)(L)(c_f)(E_f) = (\_\_\_)(\_\_\_)(\_\_\_)(\_\_\_)$ __________$
(1 - line 44)x(line 43)x(line 13)x(line 60)

65. C_T = (line 61)+(line 62)+(line 63)+(line 64)-(line 31)

__________$

Total Cost for Non-Solar System

66. $C_{oc}E_o$ = (line 40)x(line 58) __________$

67. $Lc_{fc}E_f$ = (line 43)x(line 14)x(line 60)
(maintenance cost neglected) __________$

68. C_{TC} = (line 66 + line 67) __________$

Present Value of Life-Cycle Cost Savings
With Solar System

69. Savings = (line 68 - line 65) __________$

WORKSHEET LCA-3

In Worksheet LCA-3, column [1] is the year into the future for which the analysis may be made. A reasonable economic analysis can be made for 15 to 20 years into the future.

Column [2] is the annual mortgage payment determined from Worksheet LCA-1, line 32. If the mortgage payment is a fixed annual amount, the payment for all future years would be the same as the first year.

Column [3] is the years remaining on the mortgage at the beginning of the year. The worksheet is for a 20-year mortgage.

Column [4] is the fraction of the mortgage payment which is paid as interest. The fraction decreases with increasing years and may be determined from the appropriate table (Tables 15-8 through 15-12) for the particular interest rate and term of the mortgage.

Column [5] is the portion of the mortgage which is paid as interest and is the product of column [2] times column [4].

Column [6] is auxiliary fuel cost. Because of expected fuel cost increases, the first year fuel cost will increase for subsequent years. The first year fuel cost is determined from Worksheet LCA-1, line 33. The second year fuel cost is determined by multiplying the first year cost by (1 + fuel inflation rate, line 20 of Worksheet LCA-1). For example, if the first year fuel cost is $400 and the fuel inflation rate is 7 percent, the second year cost is ($400 x 1.07=) $428. The fuel cost for each succeeding year is determined by multiplying the previous year by (1 + fuel inflation rate). Note that the inflation rate may be changed for each year.

Column [7] is the annual property tax. The first year tax is calculated on line 34 on Worksheet LCA-1 and succeeding years can be escalated by the general inflation rate, line 22.

Column [8] is the annual insurance premium determined on line 35 of Worksheet LCA-1. For many homeowner's insurance, the principal and premium may escalate with increasing value of the property.

Column [9] is the annual operating cost of the solar system. The operating cost for the first year is determined on line 36 of Worksheet LCA-1. The cost for each succeeding year is determined by multiplying the previous year cost by (1 + electricity inflation rate, line 21).

Column [10] is the annual maintenance cost. The first year cost is estimated on line 37 of Worksheet LCA-1. The annual increase in maintenance cost can be estimated arbitrarily, or the cost can be estimated by multiplying the previous year cost by (1 + general inflatio rate).

Column [11] is the income tax savings calculated by the product of the effective tax rate (on line 27 of Worksheet LCA-1) and the sum of annual interest paid, in column [5], plus property taxes, column [7].

Column [12] is the annual expense of a solar system and is determined by: Column [2] + column [6] + column [7] - column [8] + column [9] + column [10] - column [11]. The first year cash flow is calculated by adding the down payment and subtracting the federal tax credit.

LIFE CYCLE COST ANALYSIS
CASH FLOW

A. Mortgage interest rate ______ %/100
B. Auxiliary fuel inflation rate ______ %/100
C. General inflation rate ______ %/100

Collector area ____________ ft^2
Solar fraction of total load ____ %/100
(see Worksheet LCA-1, line 5)

System Cost $ ________
Down Payment $ ________
Federal Tax Credit $ ________

[1] Year	[2] Annual Mortgage Payment	[3] Years Left on Mortgage	[4] Frac. of Mortgage as Interest	[5] Interest Paid	[6] Auxiliary Fuel Cost	[7] Property Tax	[8] Insurance	[9] Operating Cost	[10] Maintenance Cost	[11] Income Tax Savings	[12] Expense with Solar
1		20									
2		19									
3		18									
4		17									
5		16									
6		15									
7		14									
8		13									
9		12									
10		11									
11		10									
12		9									
13		8									
14		7									
15		6									
16		5									
17		4									
18		3									
19		2									
20		1									

[2] Annual mortgage payment from LCA-1, line 32
[4] See Tables 15-8 through 15-12
[5] Column [2] x column [4]
[6] First year cost from LCA-1, line 33
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[7] See line 34, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)

[8] See line 35, LCA-1 (and use general inflation rate)
[9] First year cost see line 36, LCA-1
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[10] First year cost see line 37, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)
[11] {Column [5] + Column [7]} x line 27, LCA-1
[12] Downpayment + [2]+[6]+[7]+[8]+[9]+[10]-[11]

WORKSHEET LCA-4

Worksheet LCA-4 is used to calculate the savings for solar systems over non-solar systems for two different collector areas.

Column [1] is the year into the future for which the analysis may be made and should correspond with Worksheet LCA-3.

Column [2] is the total fuel and operating cost for the non-solar system. The first year cost is the total of lines 38 and 39 on Worksheet LCA-1. The costs in succeeding years are determined by multiplying the cost for the previous year by (1 + fuel inflation rate).

Column [3] is the present worth factor, determined from Table 15-7.

Column [4] is the present worth of the annual cost for a non-solar system.

Column [5] is the annual cost of the solar system, transferred from column [12] of Worksheet LCA-3.

Column [6] is the present value of the annual cost of the solar system determined by multiplying column [5] by column [3].

Column [7] is the present worth of savings with a solar system and is determined by column [4] - column [6].

Column [8] is the cumulative present worth of savings with a solar system and is the running sum of column [7].

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LIFE-CYCLE COST ANALYSIS
CASH FLOW AND PRESENT WORTH SUMMARIES

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	NON-SOLAR SYSTEM			SOLAR SYSTEM			
	r_f = _____	d = ____		Collector Area ____ft^2			
Year	Fuel plus Operating Expenses	Present Worth Factor	Present Worth of Annual Cost	Expense with Solar System	Present Worth of Annual Cost	Present Worth of Savings	Cumula. Present Worth of Savings
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
TOTALS							

[2] First year cost, add lines 38 and 29 of LCA-1. Second and future years: (previous year cost) x (1 + fuel inflation rate)
[3] See Table 15-7
[4] Column [2] x column [3]
[5] Column [12], Worksheet LCA-3
[6] Column [5] x column [3]
[7] Column [4] - column [6]
[8] Running sum of column [7]

EXAMPLE 15-4

Determine the life-cycle cost of the liquid-heating solar system of Example 11-1 with 500 square feet of collectors. Assume the following data apply:

1. F, annual solar fraction is 0.68

2. Seven percent of the solar energy collected is required to operate the pumps and control the system

3. c_e, current electricity cost is 3.5 ¢/kWh

4. A 20-year loan at 9 percent is obtainable with 20 percent down

5. Cost of solar system is $20/ft^2 for collector-related costs plus $3,000 for costs not related to collector area. In terms of collector area, the cost is 20 + (3000/500) or 26 $/ft^2 of collector

6. r_f, fuel inflation rate is 10 percent

7. g, general inflation rate is 6 percent

8. Homeowners insurance is available for a premium of 0.3 percent of insured value

9. Property tax is levied on an assessed value which is 30 percent of market and the mil levy is 100. This is the equivalent of a property tax levied as (0.30 x 0.1), or 3 percent of market value

10. The owner's federal income tax rate is 32 percent and the solar tax is 8 percent

11. Maintenance cost is $100 for first year

12. Use a market discount rate of 10 percent

DATA SHEET FOR ECONOMIC ANALYSIS

Project SunBody Residence

Building Data (see Worksheet B)

1. Annual space heating load — 108.3 mBtu/yr
2. Annual DHW heating load — 21.0 mBtu/yr
3. Total H and DHW load (add lines 1 and 2) — 129.3 mBtu/yr

Solar System Data (see Worksheet G)

4. Collector area — 500 ft^2
5. Fraction of annual heating load supplied from solar — 0.68 decimal
6. Total annual solar heat collected (multiply line 5 and line 3) — 87.9 mBtu/yr
7. Fraction of solar heat needed for electric power to operate the heating system (estimate, 0.06 to 0.10) — 0.07 decimal
8. Electric energy for operating (heat equivalent)(multiply line 6 by line 7) — 6.2 mBtu/yr
9. Auxiliary heating energy required (subtract line 6 from line 3) — 41.4 mBtu/yr

Non-Solar Heating System (Alternative)

10. Total annual heating load by conventional heating system (line 3) — 129.3 mBtu/yr
11. Electric energy required for operating non-solar system (heat equivalent) (estimate, 0.02 to 0.03 of line 10) — 2.6 mBtu/yr

Energy Prices

12. c_e, current energy cost for electricity (use Figure 15-2) 3.5 ¢/kWhr — 10.25 $/mBtu
13. c_f, current cost of fuel for auxiliary heating (to solar system (use Figure 15-1 or 15-2) — 10.25 $/mBtu
14. c_{fc}, current cost of fuel for non-solar system (use Figure 15-1 or 15-2) — 10.25 $/mBtu

Financial Data

15. m, term of the loan for solar system — 20 yrs
16. α, downpayment 20 % — 0.20 decimal
17. i, interest rate on loan 9 % — 0.09 decimal
18. Annual mortgage rate for loan (from Figure 15-4 or standard mortgage loan tables) — 0.11 decimal

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Economic Data

19. C_a, installed cost of solar system per unit area	26	$/ft^2
20. r_f, estimated auxiliary fuel inflation rate	10	%
21. r_e, estimated electric energy inflation rate	10	%
22. g, estimated general inflation rate	6	%
23. p, property tax rate (based on market value)	0.03	decimal
24. h, insurance premium rate	0.003	decimal
25. Federal income tax rate for owner	0.32	decimal
26. State income tax rate for owner	0.08	decimal
27. t, effective income tax rate {i.e., (line 25) + (line 26) - [2 x (line 25) x (line 26)]}	0.35	decimal
28. d, market discount rate	0.10	decimal

Solar System Cost Items

29. Installed cost (multiply line 4 500 by line 19 26)	13,000	$
30. Downpayment (multiply line 29 13,000 by 16 0.20)	2600	$
31. Federal tax credit for solar (30% of first $2000 plus 20% of next $8000)	2200	$
32. Amount of loan (line 29 minus line 30)	10,400	$
33. Annual mortgage payment (multiply line 32 by line 18)	1,144	$/yr
34. C_f, first year cost of auxiliary heating (multiply line 9 by line 13)	424	$/yr
35. First year property tax (multiply line 29 by 23)	390	$/yr
36. First year insurance premium (multiply line 29 by line 24)	39	$/yr
37. C_o, first year cost of operating the solar system (multiply line 8 by line 12)	64	$/yr
38. C_m, first year maintenance cost	100	$/yr

Non-Solar System Cost Items

39. C_{fc}, first year cost of fuel for non-solar system (multiply line 10 by line 14)	1325	$/yr
40. C_{oc}, first year cost of operating non-solar system (multiply line 11 by line 12) 105	27	$/yr

LIFE-CYCLE COST ANALYSIS

Total Cost for Solar System

41.	n, total years of analysis	20 yrs
42.	A, collector area	500 ft^2
43.	L, annual heat load	129.3 MMBtu
44.	F, fraction of annual heat provided by the solar system (line 5)	.68 decimal
45.	P/X (d,g,n) = P/X (10, 6, 20) (line 28, line 22, line 41)	13.082
46.	P/X (d,0,m) = P/X (10, 0, 20) (line 28, 0, line 15)	8.514
47.	P/X (i,0,m) = P/X (9, 0, 20) (line 17, 0, line 15)	9.176
48.	P/X (d,i,m) = P/X (10, 9, 20) (line 28, line 17, line 15	16.770
49.	P/X (0,i,m) = P/X (0 , 9, 20) (0, line 17, line 15)	51.518
50.	$(t)\left[\frac{P/X\ (d,i,m)}{P/X\ (0,i,m)}\right] = \left(\frac{\text{line 27} \times \text{line 48}}{\text{line 49}}\right)$	0.114
51.	$(1-t)\left[\frac{P/X\ (d,0,m)}{P/X\ (i,0,m}\right)] = \frac{(1-\text{line 27})(\text{line 46})}{\text{line 47}}$	0.603
52.	Add: line 50 + line 51	0.717
53.	1 - α (1 - line 16)	0.8
54.	Multiply: line 52 x line 53	0.574
55.	(1 - t)(p) + h (1 - line 27)(line 23) + (line 24)	0.0225
56.	Multiply: line 55 x line 45	0.294
57.	E_1 = (line 16) + (line 56) + (line 54)	1.068
58.	E_0 = P/X (d,r_0,n) = P/X (10, 10, 20) = P/X (line 28, line 21, line 41)	18.182
59.	E_m = P/X (d,r_m,n) = P/X (10, 6, 20) = P/X (line 28, line 22, line 41)	13.082

60. E_f = P/X (d, r_r, n) = P/X (10, 10. 20)
= P/X (line 28, line 20, line 41) 18,182

61. $(A)(C_a)(E_1)$ = (line 42)x(line 19)x(line 57) 13,884 $

62. C_oE_o = (line 37)x(line 58) 1,164 $

63. C_mE_m = (line 38)x(line 59) 1,308 $

64. $(1-F)(L)(c_f)(E_f)$ = (.32)(129.3)(10.25)(18.182) 7,711 $
(1 - line 44)x(line 43)x(line 13)x(line 60)

65. C_T = (line 61)+(line 62)+(line 63)+(line 64)-(line 31)

21,867 $

Total Cost for Non-Solar System

66. $C_{oc}E_o$ = (line 40)x(line 58) 491 $

67. $Lc_{fc}E_f$ = (line 43)x(line 14)x(line 60)
(maintenance cost neglected) 24,097 $

68. C_{TC} = (line 66 + line 67) 24,558 $

Present Value of Life-Cycle Cost Savings
With Solar System

69. Savings = (line 68 - line 65) 2721 $

DATA SHEET FOR ECONOMIC ANALYSIS

Project________________________

Building Data (see Worksheet B)

1.	Annual space heating load	______ mBtu/yr
2.	Annual DHW heating load	______ mBtu/yr
3.	Total H and DHW load (add lines 1 and 2)	______ mBtu/yr

Solar System Data (see Worksheet G)

4.	Collector area	______ ft^2
5.	Fraction of annual heating load supplied from solar	______ decimal
6.	Total annual solar heat collected (multiply line 5 and line 3)	______ mBtu/yr
7.	Fraction of solar heat needed for electric power to operate the heating system (estimate, 0.06 to 0.10)	______ decimal
8.	Electric energy for operating (heat equivalent)(multiply line 6 by line 7)	______ mBtu/yr
9.	Auxiliary heating energy required (subtract line 6 from line 3)	______ mBtu/yr

Non-Solar Heating System (Alternative)

10.	Total annual heating load by conventional heating system (line 3)	______ mBtu/yr
11.	Electric energy required for operating non-solar system (heat equivalent) (estimate, 0.02 to 0.03 of line 10)	______ mBtu/yr

Energy Prices

12.	c_e, current energy cost for electricity (use Figure 15-2) ______¢/kWhr	______ $/mBtu
13.	c_f, current cost of fuel for auxiliary heating (to solar system (use Figure 15-1 or 15-2)	______ $/mBtu
14.	c_{fc}, current cost of fuel for non-solar system (use Figure 15-1 or 15-2)	______ $/mBtu

Financial Data

15.	m, term of the loan for solar system	______ yrs
16.	α, downpayment ______%	______ decimal
17.	i, interest rate on loan ______%	______ decimal
18.	Annual mortgage rate for loan (from Figure 15-4 or standard mortgage loan tables)	______ decimal

Economic Data

19. C_a, installed cost of solar system per unit area ____________ $/ft^2
20. r_f, estimated auxiliary fuel inflation rate ____________ %
21. r_e, estimated electric energy inflation rate ____________ %
22. g, estimated general inflation rate ____________ %
23. p, property tax rate (based on market value) ____________ decimal
24. h, insurance premium rate ____________ decimal
25. Federal income tax rate for owner ____________ decimal
26. State income tax rate for owner ____________ decimal
27. t, effective income tax rate {i.e., (line 25) + (line 26) - [2 x (line 25) x (line 26)]} ____________ decimal
28. d, market discount rate ____________ decimal

Solar System Cost Items

29. Installed cost (multiply line 4 _______ by line 19 _______) ____________ $
30. Downpayment (multiply line 29 _______ by 16 _______) ____________ $
31. Federal tax credit for solar (30% of first $2000 plus 20% of next $8000) ____________ $
32. Amount of loan (line 29 minus line 30) ____________ $
33. Annual mortgage payment (multiply line 32 by line 18) ____________ $/yr
34. C_f, first year cost of auxiliary heating (multiply line 9 by line 13) ____________ $/yr
35. First year property tax (multiply line 29 by 23) ____________ $/yr
36. First year insurance premium (multiply line 29 by line 24) ____________ $/yr
37. C_o, first year cost of operating the solar system (multiply line 8 by line 12) ____________ $/yr
38. C_m, first year maintenance cost ____________ $/yr

Non-Solar System Cost Items

39. C_{fc}, first year cost of fuel for non-solar system (multiply line 10 by line 14) ____________ $/yr
40. C_{oc}, first year cost of operating non-solar system (multiply line 11 by line 12) ____________ $/yr

LIFE-CYCLE COST ANALYSIS

Total Cost for Solar System

41.	n, total years of analysis	______ yrs
42.	A, collector area	______ ft^2
43.	L, annual heat load	______ MMBtu
44.	F, fraction of annual heat provided by the solar system (line 5)	______ decimal
45.	P/X (d,g,n) = P/X (___, ___, ___) (line 28, line 22, line 41)	______
46.	P/X (d,0,m) = P/X (___, 0, ___) (line 28, 0, line 15)	______
47.	P/X (i,0,m) = P/X (___, 0, ___) (line 17, 0, line 15)	______
48.	P/X (d,i,m) = P/X (___, ___, ___) (line 28, line 17, line 15	______
49.	P/X (0,i,m) = P/X (0 , ___, ___) (0, line 17, line 15)	______
50.	$(t)[\frac{P/X\ (d,i,m)}{P/X\ (0,i,m)}] = (\frac{\text{line 27 x line 48}}{\text{line 49}})$	______
51.	$(1-t)[\frac{P/X\ (d,0,m)}{P/X\ (i,0,m})] = \frac{\text{(1-line 27)(line 46)}}{\text{line 47}}$	______
52.	Add: line 50 + line 51	______
53.	1 - α (1 - line 16)	______
54.	Multiply: line 52 x line 53	______
55.	(1 - t)(p) + h (1 - line 27)(line 23) + (line 24)	______
56.	Multiply: line 55 x line 45	______
57.	E_1 = (line 16) + (line 56) + (line 54)	______
58.	E_o = P/X (d,r_o,n) = P/X (___, ___, ___) = P/X (line 28, line 21, line 41)	______
59.	E_m = P/X (d,r_m,n) = P/X (___, ___, ___) = P/X (line 28, line 22, line 41)	______

60. E_f = P/X (d, r_r, n) = P/X (___, ___. ___)
= P/X (line 28, line 20, line 41) ____________

61. $(A)(C_a)(E_1)$ = (line 42)x(line 19)x(line 57) ____________$

62. C_oE_o = (line 37)x(line 58) ____________$

63. C_mE_m = (line 38)x(line 59) ____________$

64. $(1-F)(L)(c_f)(E_f)$ = (____)(____)(____)(____) ____________$
(1 - line 44)x(line 43)x(line 13)x(line 60)

65. C_T = (line 61)+(line 62)+(line 63)+(line 64)-(line 31)

____________$

Total Cost for Non-Solar System

66. $C_{oc}E_o$ = (line 40)x(line 58) ____________$

67. $Lc_{fc}E_f$ = (line 43)x(line 14)x(line 60)
(maintenance cost neglected) ____________$

68. C_{TC} = (line 66 + line 67) ____________$

Present Value of Life-Cycle Cost Savings
With Solar System

69. Savings = (line 68 - line 65) ____________$

LIFE CYCLE COST ANALYSIS
CASH FLOW

A. Mortgage interest rate 9 %/100
B. Auxiliary fuel inflation rate 10 %/100
C. General inflation rate 6 %/100

Collector area 500 ft^2
Solar fraction of total load 68 %/100
(see Worksheet LCA-1, line 5)

System Cost $13,000
Down Payment $ 2,600
Federal Tax Credit $ 2,200

[1] Year	[2] Annual Mortgage Payment	[3] Years Left on Mortgage	[4] Frac. of Mortgage as Interest	[5] Interest Paid	[6] Auxiliary Fuel Cost	[7] Property Tax	[8] Insurance	[9] Operating Cost	[10] Maintenance Cost	[11] Income Tax Savings	[12] Expense with Solar
1	1144	20	.822	940	424	390	39	64	100	466	2095
2	1144	19	.806	922	466	413	41	70	106	467	1773
3	1144	18	.788	901	513	438	44	77	112	469	1859
4	1144	17	.769	880	564	464	46	85	119	472	1950
5	1144	16	.748	856	621	492	49	94	126	473	2053
6	1144	15	.725	829	683	522	52	103	134	474	2164
7	1144	14	.701	802	751	553	55	113	142	475	2283
8	1144	13	.674	771	826	586	59	125	150	476	2414
9	1144	12	.644	737	909	622	62	137	159	476	2557
10	1144	11	.612	700	1000	659	66	151	169	476	2713
11	1144	10	.578	661	1100	698	70	166	179	476	2881
12	1144	9	.540	618	1210	740	74	183	190	475	3066
13	1144	8	.498	570	1331	785	78	201	201	474	3266
14	1144	7	.453	518	1464	832	83	221	213	473	3484
15	1144	6	.404	462	1610	882	88	243	226	470	3723
16	1144	5	.350	400	1771	935	93	267	240	467	3983
17	1144	4	.292	334	1948	991	99	294	254	464	4266
18	1144	3	.228	261	2143	1060	105	323	269	462	4582
19	1144	2	.158	181	2357	1113	111	356	285	4[illegible]	4913
20	1144	1	.083	95	2593	1180	118	391	303	446	5283

[2] Annual mortgage payment from LCA-1, line 32
[4] See Tables 15-8 through 15-12
[5] Column [2] x column [4]
[6] First year cost from LCA-1, line 33
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[7] See line 34, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)

[8] See line 35, LCA-1 (and use general inflation rate)
[9] First year cost see line 36, LCA-1
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[10] First year cost see line 37, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)
[11] (Column [5] + Column [7]) x line 27, LCA-1
[12] Downpayment + [2]+[6]+[7]+[8]+[9]+[10]-[11]

LIFE-CYCLE COST ANALYSIS
CASH FLOW AND PRESENT WORTH SUMMARIES

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	NON-SOLAR SYSTEM			SOLAR SYSTEM			
	r_f = 0.10	d = 0.10		Collector Area 500 ft^2			
Year	Fuel plus Operating Expenses	Present Worth Factor	Present Worth of Annual Cost	Expense with Solar System	Present Worth of Annual Cost	Present Worth of Savings	Cumula. Present Worth of Savings
1	1352	.909	1229	2095	1904	-675	-675
2	1487	.826	1228	1773	1464	-236	-911
3	1636	.751	1229	1859	1396	-167	-1078
4	1800	.683	1229	1950	1332	-103	-1181
5	1979	.621	1229	2053	1275	-46	-1227
6	2177	.564	1228	2164	1220	68	-1219
7	2395	.513	1229	2283	1171	58	-1161
8	2635	.467	1231	2414	1127	104	-1057
9	2898	:424	1229	2557	1084	145	-912
10	3188	.386	1231	2713	1047	184	-728
11	3507	.350	1227	2881	1008	219	-509
12	3857	.319	1230	3066	978	252	-257
13	4243	.290	1230	3266	947	283	26
14	4667	.263	1227	3484	916	311	337
15	5134	.239	1227	3734	890	337	674
16	5648	.218	1231	3983	868	363	1037
17	6212	.198	1230	4266	845	385	1422
18	6834	.180	1230	4582	825	405	1827
19	7517	.164	1233	4913	806	427	2254
20	8269	.149	1232	5283	787	445	2699
TOTALS	77,435		24,589	61,308	21,890		

[2] First year cost, add lines 38 and 29 of LCA-1. Second and future years: (previous year cost) x (1 + fuel inflation rate)
[3] See Table 15-7
[4] Column [2] x column [3]
[5] Column [12], Worksheet LCA-3
[6] Column [5] x column [3]
[7] Column [4] - column [6]
[8] Running sum of column [7]

LIFE CYCLE COST ANALYSIS
CASH FLOW

A. Mortgage interest rate ________ %/100
B. Auxiliary fuel inflation rate ________ %/100
C. General inflation rate ________ %/100

Collector area ________________ ft^2
Solar fraction of total load ____ %/100
(see Worksheet LCA-1, line 5)

System Cost $________
Down Payment $________
Federal Tax Credit $________

[1] Year	[2] Annual Mortgage Payment	[3] Years Left on Mortgage	[4] Frac. of Mortgage as Interest	[5] Interest Paid	[6] Auxiliary Fuel Cost	[7] Property Tax	[8] Insurance	[9] Operating Cost	[10] Maintenance Cost	[11] Income Tax Savings	[12] Expense with Solar
1		20									
2		19									
3		18									
4		17									
5		16									
6		15									
7		14									
8		13									
9		12									
10		11									
11		10									
12		9									
13		8									
14		7									
15		6									
16		5									
17		4									
18		3									
19		2									
20		1									

[2] Annual mortgage payment from LCA-1, line 32
[4] See Tables 15-8 through 15-12
[5] Column [2] x column [4]
[6] First year cost from LCA-1, line 33
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[7] See line 34, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)

[8] See line 35, LCA-1 (and use general inflation rate)
[9] First year cost see line 36, LCA-1
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[10] First year cost see line 37, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)
[11] (Column [5] + Column [7]) x line 27, LCA-1
[12] Downpayment + [2]+[6]+[7]+[8]+[9]+[10]-[11]

LIFE-CYCLE COST ANALYSIS
CASH FLOW AND PRESENT WORTH SUMMARIES

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	NON-SOLAR SYSTEM			SOLAR SYSTEM			
	r_f = ____	d = ____		Collector Area ____ ft^2			
Year	Fuel plus Operating Expenses	Present Worth Factor	Present Worth of Annual Cost	Expense with Solar System	Present Worth of Annual Cost	Present Worth of Savings	Cumula. Present Worth of Savings
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
TOTALS							

[2] First year cost, add lines 38 and 29 of LCA-1. Second and future years: (previous year cost) x (1 + fuel inflation rate)
[3] See Table 15-7
[4] Column [2] x column [3]
[5] Column [12], Worksheet LCA-3
[6] Column [5] x column [3]
[7] Column [4] - column [6]
[8] Running sum of column [7]

LIFE CYCLE COST ANALYSIS
CASH FLOW

A. Mortgage interest rate ______ %/100
B. Auxiliary fuel inflation rate ______ %/100
C. General inflation rate ______ %/100

Collector area ______ ft^2
Solar fraction of total load ____ %/100
(see Worksheet LCA-1, line 5)

System Cost $ ______
Down Payment $ ______
Federal Tax Credit $ ______

[1] Year	[2] Annual Mortgage Payment	[3] Years Left on Mortgage	[4] Frac. of Mortgage as Interest	[5] Interest Paid	[6] Auxiliary Fuel Cost	[7] Property Tax	[8] Insurance	[9] Operating Cost	[10] Maintenance Cost	[11] Income Tax Savings	[12] Expense with Solar
1		20									
2		19									
3		18									
4		17									
5		16									
6		15									
7		14									
8		13									
9		12									
10		11									
11		10									
12		9									
13		8									
14		7									
15		6									
16		5									
17		4									
18		3									
19		2									
20		1									

[2] Annual mortgage payment from LCA-1, line 32
[4] See Tables 15-8 through 15-12
[5] Column [2] x column [4]
[6] First year cost from LCA-1, line 33
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[7] See line 34, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)

[8] See line 35, LCA-1 (and use general inflation rate)
[9] First year cost see line 36, LCA-1
Second and future years:
(previous year cost) x (1 + fuel inflation rate)
[10] First year cost see line 37, LCA-1
Second and future years:
(previous year cost) x (1 + general inflation rate)
[11] (Column [5] + Column [7]) x line 27, LCA-1
[12] Downpayment + [2]+[6]+[7]+[8]+[9]+[10]-[11]

LIFE-CYCLE COST ANALYSIS
CASH FLOW AND PRESENT WORTH SUMMARIES

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	NON-SOLAR SYSTEM			SOLAR SYSTEM			
	r_f = ____	d = ____		Collector Area ____ ft^2			
Year	Fuel plus Operating Expenses	Present Worth Factor	Present Worth of Annual Cost	Expense with Solar System	Present Worth of Annual Cost	Present Worth of Savings	Cumula. Present Worth of Savings
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
TOTALS							

[2] First year cost, add lines 38 and 29 of LCA-1. Second and future years: (previous year cost) x (1 + fuel inflation rate)
[3] See Table 15-7
[4] Column [2] x column [3]
[5] Column [12], Worksheet LCA-3
[6] Column [5] x column [3]
[7] Column [4] - column [6]
[8] Running sum of column [7]

DATA SHEET FOR ECONOMIC ANALYSIS

Project ______________________

Building Data (see Worksheet B)

1. Annual space heating load ______________ mBtu/yr
2. Annual DHW heating load ______________ mBtu/yr
3. Total H and DHW load (add lines 1 and 2) ______________ mBtu/yr

Solar System Data (see Worksheet G)

4. Collector area ______________ ft^2
5. Fraction of annual heating load supplied from solar ______________ decimal
6. Total annual solar heat collected (multiply line 5 and line 3) ______________ mBtu/yr
7. Fraction of solar heat needed for electric power to operate the heating system (estimate, 0.06 to 0.10) ______________ decimal
8. Electric energy for operating (heat equivalent)(multiply line 6 by line 7) ______________ mBtu/yr
9. Auxiliary heating energy required (subtract line 6 from line 3) ______________ mBtu/yr

Non-Solar Heating System (Alternative)

10. Total annual heating load by conventional heating system (line 3) ______________ mBtu/yr
11. Electric energy required for operating non-solar system (heat equivalent) (estimate, 0.02 to 0.03 of line 10) ______________ mBtu/yr

Energy Prices

12. c_e, current energy cost for electricity (use Figure 15-2) ______ ¢/kWhr ______________ \$/mBtu
13. c_f, current cost of fuel for auxiliary heating (to solar system (use Figure 15-1 or 15-2) ______________ \$/mBtu
14. c_{fc}, current cost of fuel for non-solar system (use Figure 15-1 or 15-2) ______________ \$/mBtu

Financial Data

15. m, term of the loan for solar system ______________ yrs
16. α, downpayment ______ % ______________ decimal
17. i, interest rate on loan ______ % ______________ decimal
18. Annual mortgage rate for loan (from Figure 15-4 or standard mortgage loan tables) ______________ decimal

Economic Data

19. C_a, installed cost of solar system per unit area ________ $/ft²
20. r_f, estimated auxiliary fuel inflation rate ________ %
21. r_e, estimated electric energy inflation rate ________ %
22. g, estimated general inflation rate ________ %
23. p, property tax rate (based on market value) ________ decimal
24. h, insurance premium rate ________ decimal
25. Federal income tax rate for owner ________ decimal
26. State income tax rate for owner ________ decimal
27. t, effective income tax rate {i.e., (line 25) + (line 26) - [2 x (line 25) x (line 26)]} ________ decimal
28. d, market discount rate ________ decimal

Solar System Cost Items

29. Installed cost (multiply line 4 ________ by line 19 ________) ________ $
30. Downpayment (multiply line 29 ________ by 16 ________) ________ $
31. Federal tax credit for solar (30% of first $2000 plus 20% of next $8000) ________ $
32. Amount of loan (line 29 minus line 30) ________ $
33. Annual mortgage payment (multiply line 32 by line 18) ________ $/yr
34. C_f, first year cost of auxiliary heating (multiply line 9 by line 13) ________ $/yr
35. First year property tax (multiply line 29 by 23) ________ $/yr
36. First year insurance premium (multiply line 29 by line 24) ________ $/yr
37. C_o, first year cost of operating the solar system (multiply line 8 by line 12) ________ $/yr
38. C_m, first year maintenance cost ________ $/yr

Non-Solar System Cost Items

39. C_{fc}, first year cost of fuel for non-solar system (multiply line 10 by line 14) ________ $/yr
40. C_{oc}, first year cost of operating non-solar system (multiply line 11 by line 12) ________ $/yr

LIFE-CYCLE COST ANALYSIS

Total Cost for Solar System

41. n, total years of analysis ______ ______yrs

42. A, collector area ____________ft^2

43. L, annual heat load ____________MMBtu

44. F, fraction of annual heat provided by the solar system (line 5) ____________decimal

45. P/X (d,g,n) = P/X (___, ___, ___)
    (line 28, line 22, line 41) ____________

46. P/X (d,0,m) = P/X (___, 0, ___)
    (line 28, 0, line 15) ____________

47. P/X (i,0,m) = P/X (___, 0, ___)
    (line 17, 0, line 15) ____________

48. P/X (d,i,m) = P/X (___, ___, ___)
    (line 28, line 17, line 15 ____________

49. P/X (0,i,m) = P/X (0 , ___, ___)
    (0, line 17, line 15) ____________

50. $(t)[\frac{P/X\ (d,i,m)}{P/X\ (0,i,m)}] = (\frac{\text{line 27 x line 48}}{\text{line 49}})$ ____________

51. $(1-t)[\frac{P/X\ (d,0,m)}{P/X\ (i,0,m}] = \frac{\text{(1-line 27)(line 46)}}{\text{line 47}}$ ____________

52. Add: line 50 + line 51 ____________

53. 1 - α (1 - line 16) ____________

54. Multiply: line 52 x line 53 ____________

55. (1 - t)(p) + h
    (1 - line 27)(line 23) + (line 24) ____________

56. Multiply: line 55 x line 45 ____________

57. E_1 = (line 16) + (line 56) + (line 54) ____________

58. E_0 = P/X (d,r_0,n) = P/X (___, ___, ___)
    = P/X (line 28, line 21, line 41) ____________

59. E_m = P/X (d,r_m,n) = P/X (___, ___, ___)
    = P/X (line 28, line 22, line 41) ____________

60. E_f = P/X (d, r_r, n) = P/X (___, ___. ___)

= P/X (line 28, line 20, line 41) __________

61. $(A)(C_a)(E_1)$ = (line 42)x(line 19)x(line 57) __________$

62. $C_o E_o$ = (line 37)x(line 58) __________$

63. $C_m E_m$ = (line 38)x(line 59) __________$

64. $(1-F)(L)(c_f)(E_f)$ = (____)(____)(____)(____) __________$
(1 - line 44)x(line 43)x(line 13)x(line 60)

65. C_T = (line 61)+(line 62)+(line 63)+(line 64)-(line 31)

__________$

Total Cost for Non-Solar System

66. $C_{oc} E_o$ = (line 40)x(line 58) __________$

67. $Lc_{fc} E_f$ = (line 43)x(line 14)x(line 60)
(maintenance cost neglected) __________$

68. C_{TC} = (line 66 + line 67) __________$

Present Value of Life-Cycle Cost Savings
With Solar System

69. Savings = (line 68 - line 65) __________$

16 INSTALLATION AND RETROFIT CONSIDERATIONS

(Modules 18 and 19, Installation Manual; Module 21, Design Manual)

The cost of labor for installing a solar system is a large part of the total system cost. Therefore careful planning of an installation can contribute significantly to lowering costs and improving the economic viability of solar space and domestic hot water systems. There are many important considerations in installation practices which affect not only initial costs, but operating and maintenance costs as well, and the latter can be, in the long term, as important as the first cost of the system.

Whether the installation is in a new structure or a retrofit into an existing building, there are common concerns. There are many additional factors in a retrofit installation which may limit the options in locating collectors, storage or other system components which deserve some explanation.

The purpose of the three modules in the training courses which concern installation of systems in new and old buildings is to make the trainees aware of preferred installation practices for solar systems. The trainee should be particularly aware of the logical sequence for installing various components, i.e. scheduling, and recognize items of specific concern for retrofit installations.

There are issues with local building codes that should be mentioned by instructors. A particularly useful reference concerning installation is the HUD Intermediate Minimum Property Standards Supplement for Solar Heating and Domestic Hot Water Systems. There are particular references to collector installation and disposal capabilities of collector fluids that will bear importantly on installation practices.

Some practical experience in home building and installation of solar systems would be of great assistance in teaching the specific modules concerning installation. Contractors rarely publish articles relating their solar system installing experience and it is difficult to learn of specific practices through published literature. Many solar system manufacturers provide training for their dealers on the installation of their system. Instructors should make the trainees aware of the availability of specific manufacturer's literature concerning installation procedures of their equipment.

17 ENERGY CONSERVATION TRADE-OFFS

(Module 17, Installation Manual; Module 9, Design Manual)

Conservation of energy for home heating and cooling by incorporating more insulation in the walls and ceilings, extra windows glazing or storm windows, storm doors, and other architectural features is the emphasis in this module. The effectiveness in reducing heating loads by specific energy conservation features can be determined by calculating the heating load in a building after introduction of a particular item. The procedures for heating and cooling load calculations are described in preceding modules and should be covered prior to discussing this module.

There are three major factors which can impact on the home energy needs; building design, operation and maintenance. The major factors in building design are building orientation and material selection, including insulation thickness and window areas. Factors in operation are influenced by life styles and living habits of occupants, but most important is the temperature setting of the thermostat. An obvious maintenance factor is keeping the heating and cooling equipment at peak efficiency.

The purpose of these modules in the training courses is to point out to the trainees in a quantitative way the economical return realized by various conservation features. In the Design manual, emphasis is placed on the comparison of heat losses by introducing various combinations of insulation storm doors and windows, along with a method for determining the economic maximum cost that should be considered in energy saving features. In the Installation manual some sample economic calculations are made to illustrate the impact of energy conservation features on solar heating systems.

Energy conservation should be practiced regardless of the type of heating system used in the building, and it is important that the instructor emphasizes the economic limits for energy conservation. After energy conservation features are introduced, the size of the solar system can be determined.

18 BUYER'S GUIDE (INCLUDING CONSTRAINTS AND INCENTIVES)

(Modules 20 and 21, Installation Manual; Module 23, Design Manual)

The Buyer's Guide is basically a summary and set of conclusions and recommendations based on the entire course. The information developed for collectors, storage units, controls and the integrated solar heating systems is utilized in the selection and appraisal of solar components and systems for practical use. The most important considerations under each topic are collected and presented in a format which should be helpful to the trainee in identifying the type of equipment and individual suppliers for specific applications.

It is, of course, difficult to recommend specific commercial products over competing equipment. Performance data and costs are usually not fully available, and even when they are presented by the manufacturer, they may have only slight resemblence to a total installed price and real thermal output of the operating system. Not only are standards and certifications still in process of development, but also the manufacturer may have little or no control or cognizance of the quality and effectiveness of the complete system finally installed in a building.

As a guide to the trainee, a number of products, such as collectors and controllers, of leading manufacturers, are listed. The instructor may want to add to or subtract from the list, depending upon his experience and geographic location. Inclusion of a product on one of these lists does not imply quality or performance superior to some products not on the lists, but rather that a considerable number of those products have been sold and put into practical use. As time passes, the membership of the lists would be expected to change with additions and deletions.

Some of the cautions that a buyer should exercise in the selection of equipment are included in this manual. Until standards and certifications are available, (progress toward both determinations are being made), the buyer will have to be cautious and capable in identifying good products versus poor products, seeking professional advice when and where he can do so. A heating contractor, or specifying engineer, must be exceptionally well versed in the matter of product selection, because his reputation depends on his ability to make sound judgements. Particular attention should be given to warranties, both with respect to duration and to detail. In this connection, the financial soundness of the company providing the warranty needs to be evaluated, because the warranty of a bankrupt company is worthless.

The module outlines, in considerable detail, the advantages and disadvantages of air and liquid solar collection systems. The instructor may have a preference of one over the other, but experience with teaching the course has shown that impartial treatment of these types is desirable so that the trainee can make his own choice, based on the facts clearly presented in the manuals.

In the presentation of this module, the instructor is advised to bring late information into the material as it develops. The field is changing rapidly, and current examples should be used where possible. In the manuals used in the past, an assortment of manufacturers' data sheets for collectors, controls, solar water heaters, and complete space heating systems has been included. It is recommended that these materials continue to be provided. The objective of the course is to furnish the trainee with sufficient information through the course and through this module to make prudent purchases of solar heating equipment, with respect to performance, durability, freedom from maintenance and economy.

In the Installer's manual, a short section (Module 20) on constraints and incentives in solar heating applications is included mainly for the purpose of providing an understanding of some of the non-technical problems which buyers and sellers of solar heating equipment may face. From the sellers' standpoint, probably the biggest obstacle to the use of solar heating is the lack of understanding by the public as to its characteristics--primarily its capabilities and limitations. The average homeowner has a reasonable knowledge of a conventional space heating system, and even of the furnace or hot water boiler that may be used. So the education of the potential user of solar heating is a need which the seller (installer) probably has to meet. This situation should gradually improve with time, but considerable effort will be required.

Several other real and imagined contraints and deterrents should be understood by the trainees so that they can, in turn, convey the information to potential customers and users. These impediments include access to sunlight, zoning regulations, building codes, financing sources, and insurance matters. It cannot be expected that everybody enrolled in practical solar courses will become well acquainted in all of these areas, but a general understanding of the current status of each topic appears desirable.

Several of these subjects, as well as the incentives outlined below, are changing very rapidly. It is necessary, therefore, that instructors obtain the latest information from the proper authorities in the local region. Whether there is legislation protecting a property owner from shadows cast by a neighbor's trees or buildings, or whether easements (protective convenants) are being utilized, this should be ascertained. If financing by a bank or loan institution is being sought, the enterprising installer and seller of solar heating systems should know the institutions that are providing capital for these systems and what their requirements for permanent solar access may be. The solar trainee should realize the value of knowing building code requirements for solar in his locality, whether zoning laws aid or impede solar installations, and whether any tax and insurance practices impose possible problems.

Information on various incentives for solar use has been included in the manual because a designer or installer of solar heating systems may make a sale or lose a customer simply on the basis of an important financial incentive. The very latest information should be in the hands of the trainee, so the instructor must be in a position to provide it.

As of November 1, 1978, a maximum federal tax credit of $2200 (30 percent of the first $2000 and 20 percent of the next $8000 solar investment) has been approved by both houses of congress. Instructors and trainees should follow this legislation, because it may have a large impact on the demand and market for solar heating systems. They should be fully acquainted with the provisions of the law. The net effect of the regulation, when enacted, will be a cost-sharing by the government of 20 to 30 percent of the total equipment cost, up to $2200.

Several states have enacted legislation providing credits against state income tax payments. Other states have such legislation under consideration. Again, instructors should provide the latest information to their classes.

Another area of incentives at the present time is a limited duration solar heating and cooling demonstration program of the U.S. Department of Energy. Through HUD, the Department of Energy, and a few other government departments, the partial or total cost of the solar heating and cooling equipment in a building may be paid by the government. It is possible that the duration of this program, due to expire in 1979, will be extended. Instructors should obtain the latest information as to the status of demonstration grants under each type of program so that their classes can take advantage of those opportunities in connection with their sale and installation of solar equipment.

Many states have passed laws exempting, either partially or totally, solar heating equipment from property tax. The status of such legislation should be explained to the trainees, so that they, in turn, can communicate the information to their associates and customers.

19 RESEARCH AND DEVELOPMENT, AND FUTURE PROSPECTS

(Module 22, Installation Manual; Module 22, Design Manual)

Nearly all of the material presented in the two courses pertains to existing technology, standard practice, and the most widely used systems for solar heating. The developers of these courses have felt that mixing the discussion of new hardware not yet well established in the market with the material on more widely used systems would tend to confuse the trainee and reduce his capability to distinguish well proven equipment from types not ready for general use.

So that trainees may be aware of new developments, however, some of which may actually become marketable, the module on research and development activities in the industry and the future prospects for application of some of these developments is included as a separate section. The modules in both manuals are both reasonably current, as of June 1978, but the status of some developments is changing at a sufficiently high rate to warrant periodic review of solar news magazines such as Solar Engineering, Solar Age and Sun World. These publications provide news on new products, companies organizing and disbanding, and other solar developments.

Probably the most important new developments not in full practical use involve the several versions of evacuated tubular solar collectors. It is recommended that this topic receive most attention in this discussion. Focusing collectors of various types are not yielding encouraging results in trial installations, and considerable caution should be expressed about their becoming generally useful. Heat storage in phase change materials is equally problemmatical.

Perhaps the best approach in the teaching of this module is to emphasize what new developments are occurring rather than what their prospects are. Research is expected to yield a sizeable portion of failures, as far as practical application is concerned, whereas useful products may develop in only a few instances. The trainees may well be cautioned, however, not to automatically assume that a product is successful and commercially saleable simply because it has received a demonstration grant from the Federal Government for a first evaluation.